Second edition

The Water Module

Student resource

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Cover image: Cloudscape over the Phillipines, Astronaut photograph ISS048-E-10018 acquired on June 25, 2016 by the ISS Crew Earth Observations Facility and the Earth Science and Remote Sensing Unit, Johnson Space Center. M. Justin Wilkinson, Texas State University, Jacobs Contract at NASA-JSC.

Image Credit: NASA, Public domain. Other photos from the Gro for GooD project.

Note to educators

This booklet has been developed for use by secondary school students. It is based on a booklet developed with schools in Kwale County, Kenya which set up School Water Clubs in 2017 and tested out the information and activities that can be found in this booklet. The booklet can also be used to support classwork or projects in science or geography lessons. Students should note that there is a glossary at the back which explains the technical terms that appear in **bold font** in this resource.

Each section includes background information and instructions for a variety of related learning activities.

Items in grey boxes such as this:

> What do you want to learn about water?

are points for students to reflect on while working through the booklet.

The accompanying Educators' Guide provides additional guidance for teachers and activity leaders, for example materials required and time needed.

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The Water Module

Student resource

Underwater photo (top) by Sime Basioli on Unsplash. Classroom activity with school water club. Photo by Saskia Nowicki.

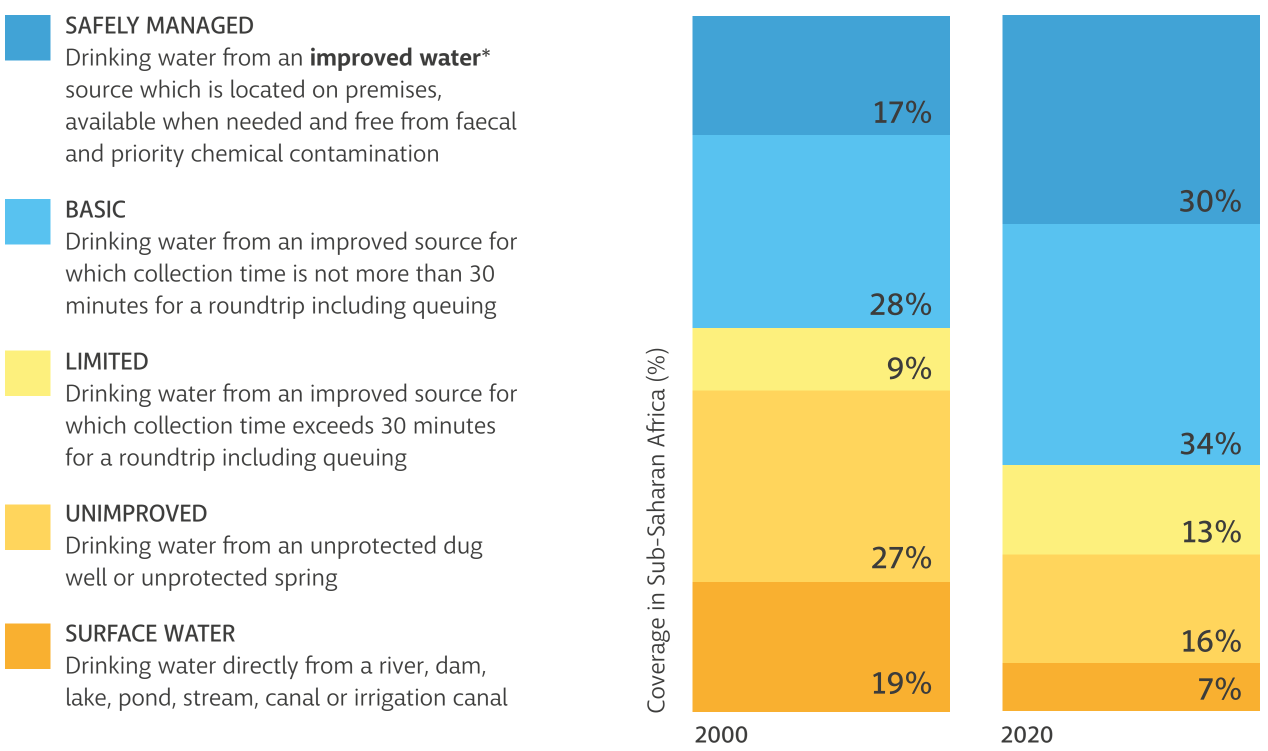
Why learn about water?

The United Nations has declared that clean drinking water is a human right, and that access to water is necessary for all other human rights to be secured. Improving access to well-managed water is one of the global Sustainable Development Goals:

SDG target 6.1:
By 2030, achieve universal and equitable access to safe and affordable drinking water for all

But there are a lot of challenges for managing water resources and water supply. Approximately one out of every four people in the world, about 25% of the global population, do not have consistent access to safe water. In Sub-Saharan Africa, about 70% of the population do not have consistent access to safe water. However, there has been progress towards safer water for more people as you can see in the bar chart below. Improvements are being made, but there is still a lot of work to do. This booklet will help you get started to understand the concepts and issues that are important for water management.

Data from WHO/UNICEF Joint Monitoring Programme. https://washdata.org/



*Find **bold** words and phrases in the glossary on page 63.

1. The water cycle

There has always been the same amount of water on Earth. It circulates continuously between the ocean, atmosphere, and land in what is called 'the water cycle.' The water cycle is a closed system. This means that water is neither created nor destroyed in natural processes on planet Earth, it only changes form between liquid, gas (water vapour), and solid (ice). **Hydrology** is the branch of science that focuses on the characteristics of water on Earth, particularly how it moves and changes form (so hydrological means 'related to the movement of water'). There are some important natural processes that create the water cycle: these are evaporation, transpiration, condensation, precipitation, infiltration, run-off, and discharge – each one appears in the figure on page 7.

> "Between earth and earth's atmosphere, the amount of water remains constant; there is never a drop more, never a drop less. This is a story of circular infinity, of a planet birthing itself."
>
> Linda Hogan, Northern Lights, 1990.

How water moves and changes form

The main source of energy that drives the water cycle is the sun. Heat energy from the sun causes **evaporation** of water from the ocean and from surface water on land. Evaporation occurs when water molecules are heated enough that they have the energy to move from a liquid form into a gas. The water **vapour** produced by evaporation rises into the atmosphere. It is joined by more water vapour that comes from plant **evapotranspiration**. This term refers to a combination of two processes: 1) evaporation from the soil and 2) **transpiration** which is a process that plants do when they release water through their leaves. Water vapour in the air is moved around by air currents and stays in the atmosphere until it becomes cold enough for **condensation** to occur.

Clouds over Kitui County, Kenya. Photo by Johanna Koehler.

Dry river bed in Kenya with farmers herding livestock. Photo licensed from Thinkstock.

When water vapour condenses, it produces clouds, which are made up entirely of tiny drops of water. If the temperature in the atmosphere rises, the drops can be evaporated and the cloud will disappear without producing any rain. If the temperature stays low enough, the drops move around within the clouds, joining-up with one another and growing until they become heavy enough to fall as **precipitation** (rain, snow, sleet or hail).

Precipitation falls into the ocean or onto the land. When it falls onto the land it can fall directly into surface **waterbodies** like lakes or **reservoirs**; it can flow over the land surface as **run-off** forming channels and eventually rivers; or it can go into the ground (a process called **infiltration**). Eventually, all surface water and groundwater will discharge into the ocean or will move directly into the atmosphere through evaporation or plant transpiration, and so the cycle continues.

Climate and spatial variability

The general pattern and conditions of weather in an area over time is called the **climate**. **Climatology** is the branch of science that focuses on understanding the climate and how it changes, including determining what the climate was like in the past and predicting what it will be like in the future. The water cycle is strongly connected to the climate, so understanding climate change is important for understanding how the water cycle will change in different places. The temperature and the amount of precipitation in an area can change a lot between months, years, and decades.

In addition to climate change, in most places there is a seasonal pattern to the weather. In some months it can rain a lot and in other months it does not rain at all. In some months it is very sunny and hot, so evaporation happens quickly. Other months are colder, so evaporation is slower. Flooding can happen when there is intense rainfall (when a lot of water falls in a short time) or when there is more than normal precipitation for a long period of time. In contrast, when there is an unusually dry period – when there is less precipitation than normal for months or years – it is called a **drought**. Droughts often cause **water scarcity**, which means that there is not enough water to meet all the needs of people, animals and the environment.

Mixing zones

As you can see in the diagram on page 7, there is often an area below lakes and rivers where shallow groundwater and surface water mix together. This is called the **hyporheic zone**. It is an important habitat for fish that lay their eggs there, and many other organisms. Another mixing zone can occur in some coastal areas where the groundwater mixes with salty water as it intrudes into the ground from the ocean or sea, creating a zone of saline groundwater.

What happens to rivers when there is less than normal level of rainfall or higher than normal temperatures for a long time?

How do you think climatologists decide what is a normal amount of rain?

The rate at which water flows through the water cycle varies at different times and in different places. Sometimes it is raining in one village but not in the neighbouring village. Across the whole planet, the amount of precipitation is uneven and so are the numbers of people. This uneven distribution of water and people makes water management difficult and complicated.

In this section we are focusing on natural processes within the water cycle, but to fully understand water resources and how to manage them, we should also consider human activity within the cycle. In *Section 5: Water Management* we will revisit the water cycle with human activity included.

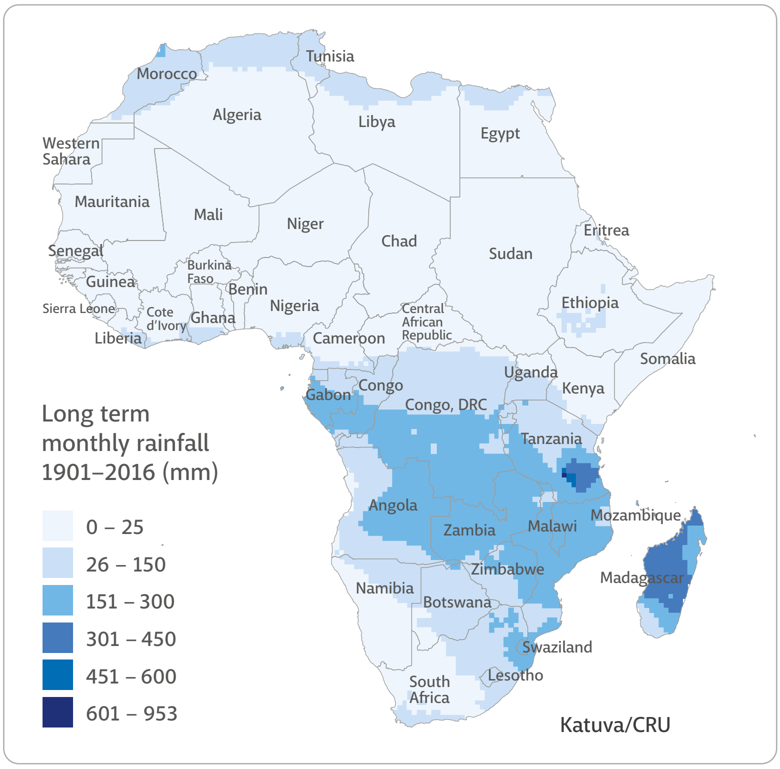
Look at the maps showing Sub-Saharan Africa. Where do you live? Do countries with more rain always have higher **population density**? What are some problems with getting too much rain or too little?

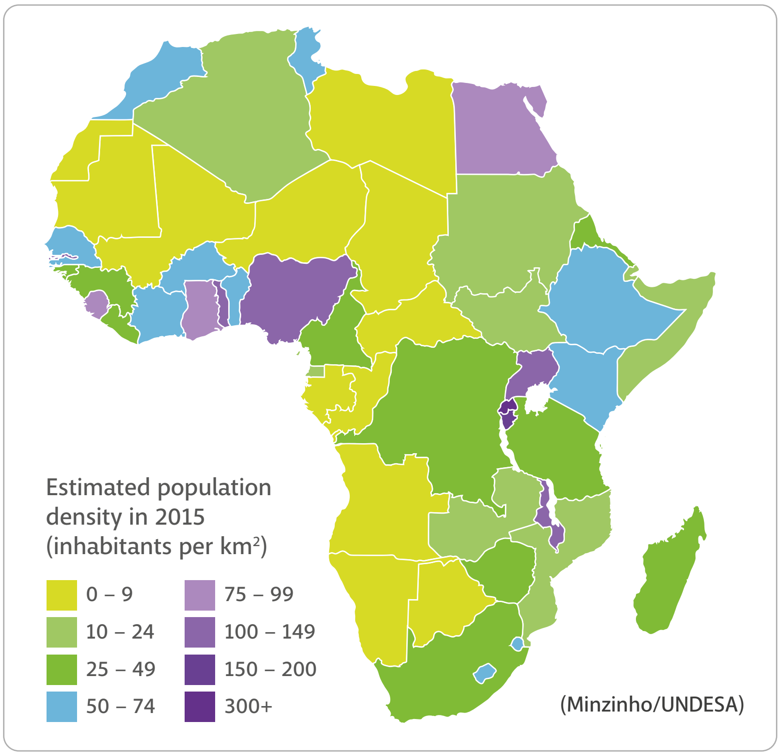
The rainfall map was created using historical data collected from 1901 to 2016. From what you know about climate change, do you think this map will look different in the future?

How long does the water cycle take?

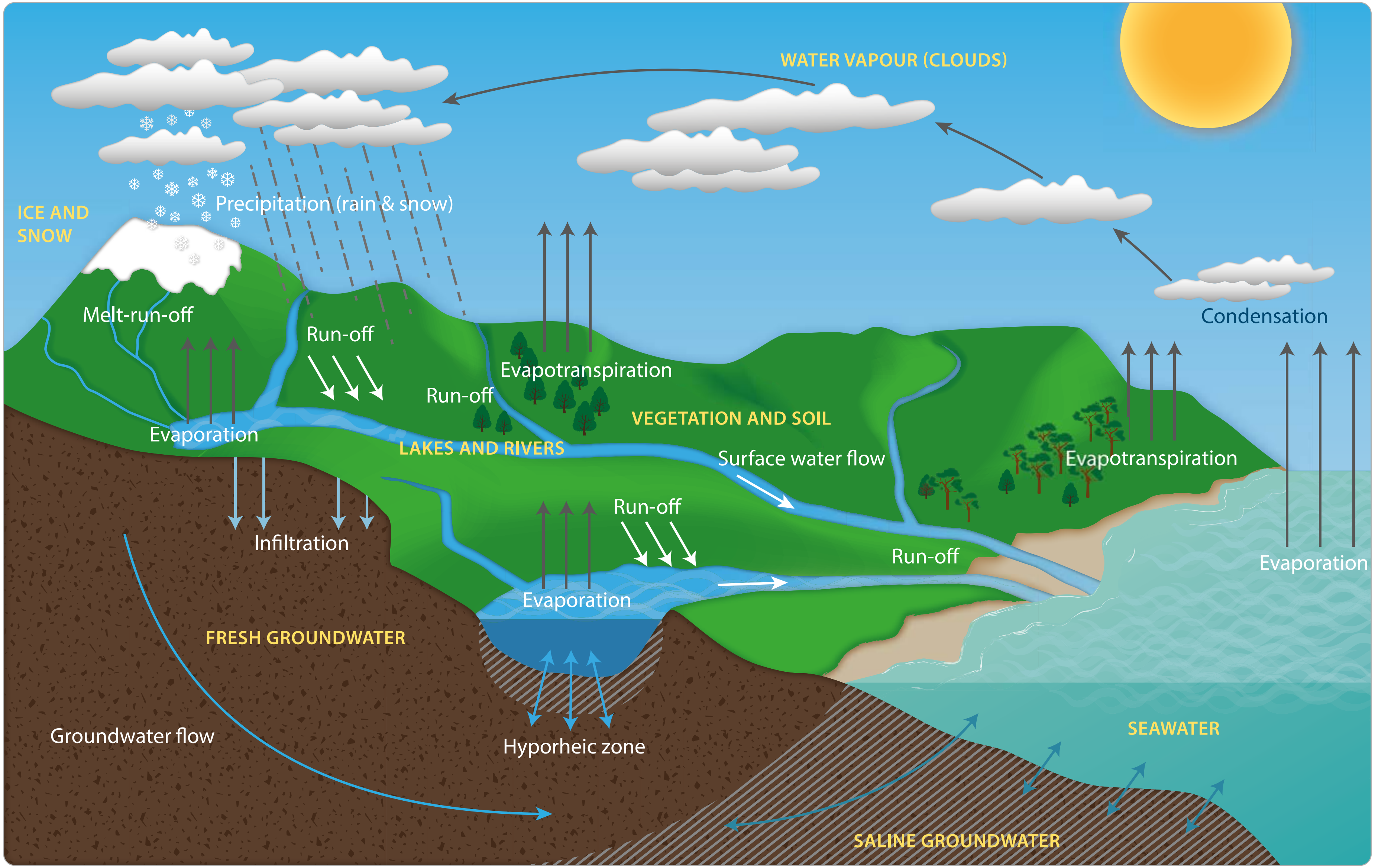
For some water (especially water that ends up deep in the ground or frozen in glaciers) the cycle back to the ocean or atmosphere takes a very long time, much longer than a human life. For other water, it takes almost no time at all – for example when rain falls on the beach the water drains back into the ocean very quickly!

Look at the maps showing Sub-Saharan Africa. Do countries with more rain always have higher population density? What are some problems with getting too much rain or too little?





The water cycle – also known as the hydrological cycle



The "natural" water cycle where I live

You could do this activity individually or in groups of 2–4. Copy and complete the table below, referring to the diagram and glossary to explore the meaning of each label.

After you have filled in the table, share it with others and find out what they wrote.

Water cycle process	Have I ever seen it with my own eyes?	Description of an example of what can be seen of this process in my local area
Surface water flow	Yes	*The river*
Precipitation	Yes	*Last time it rained!*
Condensation		
Evaporation		
Groundwater flow		
Infiltration		
Run-off		
Evapotranspiration		
Melt-run-off		

A small sip of hydrology

1 Measuring evapotranspiration:

Hydrologists study the movement of water. They want to understand everything about water flow, including the rate at which water is passing through each process in the water cycle. This activity demonstrates how this can be measured for evapotranspiration.

Equipment

- 1 small leafy plant growing in soil in a small pot or half plastic bottle
- Plastic bottle cut in half so that the bottom half is large enough to go over the top of the plant. If you do not have a plastic bottle that can cover the plant, you can use a clear (transparent) plastic bag instead.
- Marker pen
- Weighing scale (as accurate as possible)
- Stopwatch or timer
- Litre of water in jug
- Calculator
- Pencil and ruler
- Drop of food colouring

2 Measuring precipitation

To measure rainfall, hydrologists use an instrument called a raingauge. Instructions for how to build a simple raingauge should be available from your teacher or club leader.

Method

2 Use the food colouring to colour the water in the jug

3 Water the plant with the coloured water

4 Record the time of day and the weather on the worksheet. Think about what you think will happen and write down your predictions.

5 Weigh the cut bottle or clear plastic bag and record its weight to the nearest 0.1g in the cell marked (A) on the table in the worksheet.

6 Place the cut bottle or clear plastic bag over the top of the plant. If using a bag, put the mouth of the bag over the sides of the pot.

7 Set the stopwatch or timer for 15 minutes

8 When the 15 minutes is up, carefully remove the cut bottle or clear plastic bag from the plant without letting any water drip out

9 Weigh the cut bottle or clear plastic bag and record its weight on the table below.

10 Dry the cut bottle or clear plastic bag well, or use a new bag that is dry

11 Put the cut bottle or clear plastic bag back on to the plant and time again for 15 minutes. Weigh again and record.

12 Dry the cut bottle or clear plastic bag and replace for another 15 minutes before weighing again.

13 Convert weight to volume and fill in the table (1 g = 1 ml)

14 Calculate the rate of evapotranspiration

15 Calculate the average rate of evapotranspiration during the experiment

16 Discuss the questions on the worksheet and record your answers

17 Tidy up and put things away

Evapotranspiration student worksheet

Plant ID label:	Common name of plant:			
	Scientific name of plant (if known):			
	Time of day:		Weather conditions:	

Predictions

What do you predict that you will see accumulate on the bottle/bag?	

Results

Measurement period (minutes)	Weight bottle/bag (g)	Weight of water collected (g)	Volume of water (ml) (1g = 1 ml)	Rate of evapotranspiration (ml/min)
0	A)*	–	–	–
	(B)	(B-A)		
	(C)	(C-A)		
	(D)	(D-A)		

*This is where you record the initial weight of your cut bottle or bag.

Discussion

What was the average rate of evapotranspiration (ml/min) across the three measurement periods?	
What was the colour of the water that condensed on the inside of the bottle/bag and why?	
If other groups have conducted the same experiment using different species of plant, you could compare results. Did the various species have different rates of transpiration? If so, what were the physical differences in the plants? Why might this make a difference?	
How would you design an experiment to measure evaporation and transpiration separately? Would you need more equipment?	

Water cycle crossword

Test your water cycle knowledge by using the clues to fill in this crossword puzzle.

ACROSS: Clues for horizontal words:

1. Water falling out of the atmosphere in a liquid or solid state (13 letters)

5. Water flowing out; the opposite of recharge (9 letters)

6. The process by which vapour becomes a liquid often due to cooling (12 letters)

7. When there is not enough water to meet the needs of people, animals, and the environment in a region (2 words, 13 letters)

8. A body of water that forms behind a dam (9 letters)

9. Water that flows over land to surface streams, rivers, and lakes and eventually to the ocean / sea (6 letters)

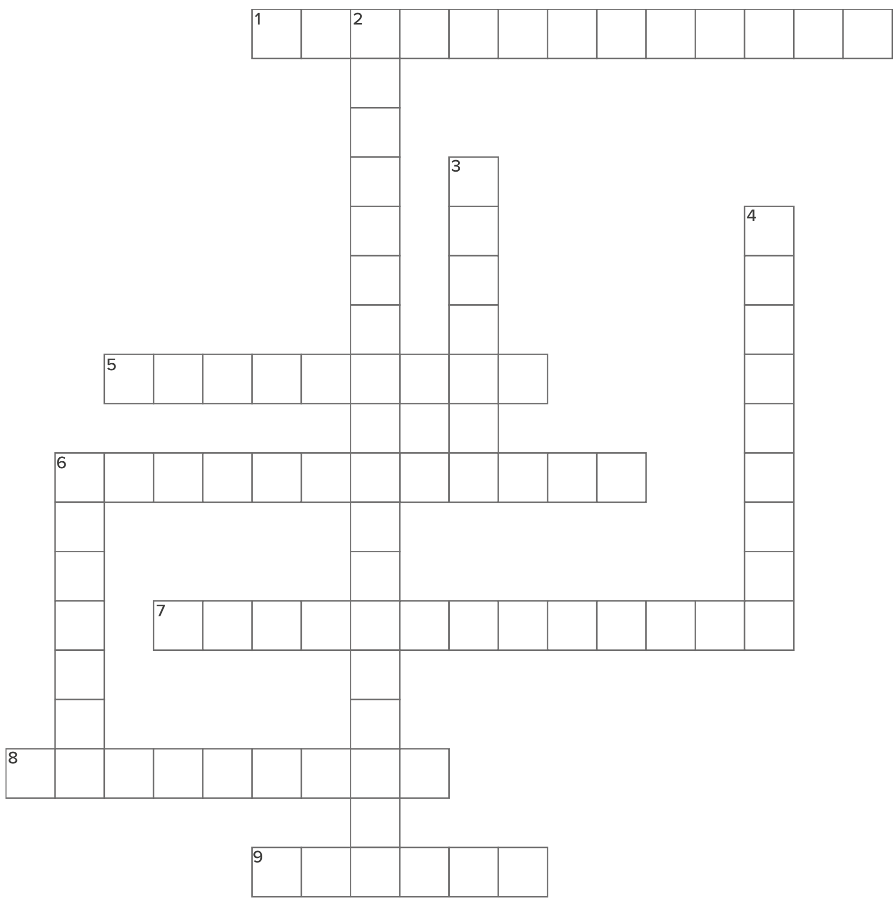
DOWN: Clues for vertical words:

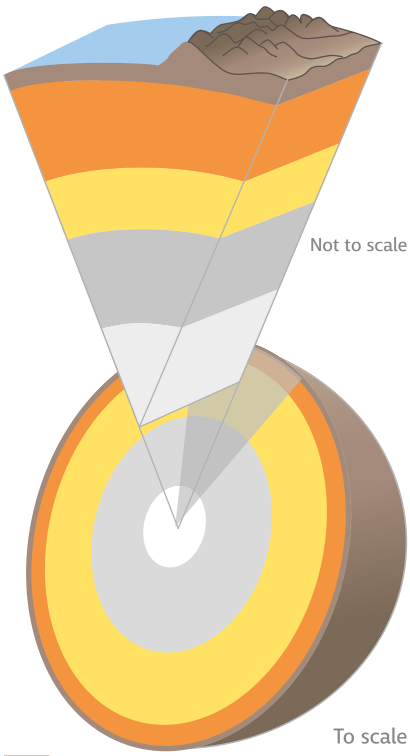
2. Movement of water vapour into the atmosphere due to both evaporation from soil and transpiration from plants (18 letters)

3. An extended period of less than normal precipitation that often affects the availability of water supplies – a natural hazard caused by climate variability (7 letters)

4. The branch of science that focuses on how water moves and changes form (9 letters)

6. The overall conditions of weather in an area over time (7 letters)





2. Geology

"Geo" means "earth" and "ology" means "a branch of knowledge" so "**geology**" is what we know about the Earth. Like hydrology, geology is a branch of science. Geologists study the physical structure and substance of the Earth. Geology is connected to water in many ways because interactions between the Earth and water impacts how landscapes form and change over time, how water is stored and moves in the ground, and how the quality of water changes when it is in the ground. .

Layers of the Earth

Most of the Earth is made up of the inner core, outer core and the mantle and it is hot – hot enough for the rock to be melted (geologists call melted rock '**molten**', this word is used when a hard material like rock or metal is so hot that it becomes a thick liquid). When volcanoes erupt we see the molten material from the mantle come to the surface. There are three main reasons why it is so hot inside the Earth: 1) when the planet first formed it was very hot and some of this original heat remains in the deep Earth; 2) the molten material moves, and this movement creates heat due to **friction**; 3) there are chemical processes in the deep Earth that produce heat.

Groundwater does not come from the core or the mantle. All the groundwater that we use is stored in the crust – the outermost layer of Earth. If the Earth was a mango, the crust would be the skin, a thin layer compared to the mantle and the core. The crust layer is cool enough so that it is solid rock. Minerals are the building blocks of rocks in the crust. They each have their own structure and combination of elements. A single rock can contain many different minerals.

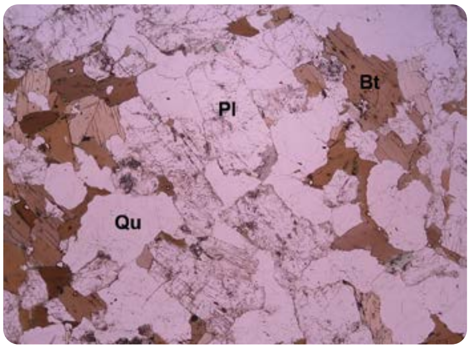
Minerals and elements

Many of the elements in the periodic table are present in minerals that form the rocks in the Earth's crust. The common ones that make up most of the crust are **oxygen** (47%), **silicon** (28%), **aluminium** (8%), **iron** (5%) and **calcium** (4%). Elements form minerals; minerals form rocks; rocks form the Earth's crust.

Elements > Minerals > Rocks > Earth's crust

Let us consider the rock in the top photo as an example. This is **granodiorite**, a type of rock found in many parts of the world including, for example, western Kenya and southeastern Cameroon. A coin is used to give an idea of size. **Granodiorite** is made up of three main minerals that interlock together. The interlocking mineral grains are very small and difficult to see. They are shown on the next image down, which is called a **photomicrograph**. This image was captured using a **microscope**, an important tool that geologists can use to magnify and study small, thin sections of rock.

The **granodiorite** minerals are **quartz** (Qu), **plagioclase feldspar** (Pl), and **biotite mica** (Bt). **Quartz** is formed by two elements: **silicon** and **oxygen**. **Plagioclase feldspar** is more complicated. It is formed from **silicon**, **oxygen** and **aluminium** as well as **calcium** or **sodium**. **Biotite** has even more elements including **potassium**, **magnesium**, **iron**, **aluminium**, **silicon**, **oxygen**, **fluorine** and **hydrogen**.

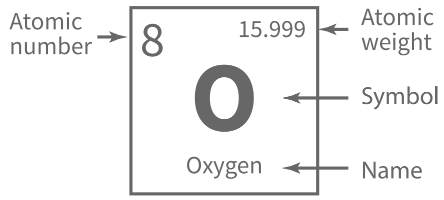


We are also interested in rocks that are made up of only one mineral. **Diamond**, for example, is a very unique mineral. It is formed from only one element: **carbon**. In some parts of the world, gemstones such as ruby are found. Ruby is also a single mineral; its scientific name is **corundum** and it is made up of **aluminium**, **oxygen** and **chromium**. Rubies are red and can be confused with garnets, which are less valuable. Examples of garnets are shown in the photo on the right (the red stones). **Garnets** are complex minerals – they all contain **silicon** and **oxygen** and two other elements, which could be **calcium**, **magnesium**, **iron**, **manganese**, **aluminium** or **chromium**.

Photos by Tom Nowicki.

> 13 elements are listed above. Can you find them in the periodic table on the next page?

The Periodic Table



1 H Hydrogen 1.008																	2 He Helium 4.0026
3 Li Lithium 6.938	4 Be Beryllium 9.012											5 B Boron 10.806	6 C Carbon 12.0096	7 N Nitrogen 14.0064	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.1797
11 Na Sodium 22.989	12 Mg Magnesium 24.304											13 Al Aluminium 26.9815	14 Si Silicon 28.084	15 P Phosphorus 30.974	16 S Sulfur 32.059	17 Cl Chlorine 35.446	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.901	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.9058	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.293
55 Cs Caesium 132.905	56 Ba Barium 137.327	57-71 Lanthanoids*	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.382	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89-103 Actinoids**	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (290)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)

*Lanthanoids	57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.9668
**Actinoids	89 Ac Actinium (227)	90 Th Thorium 232.0377	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (266)

Alkali metal | Alkaline earth metal | Lanthanide | Actinide | Transition metal | Post-transition metal

Metalloid | Polyatomic nonmetal | Diatomic nonmetal | Noble gas | Unknown chemical properties

The three categories of rocks

There are more than 3000 different minerals and hundreds of kinds of rocks, but all rocks can be divided into three categories based on how they form:

Igneous rock is formed when molten rock, also known as magma, from the mantle cools down and solidifies. This cooling happens when magma is pushed into the crust or all the way through to the Earth's surface like in a volcano. The granodiorite rock discussed in the previous section is an example of an igneous rock.

Sedimentary rock is formed by a process that is like recycling. Existing rock is broken down by wind and water, in a process called **weathering**, and the pieces become sand, mud and pebbles that can be blown by the wind or washed down rivers. Eventually these pieces stop moving and form a layer of material (often in deserts, lakes, at the end of rivers, or in the ocean). Over time, more and more pieces settle forming more and more layers. After thousands or millions of years the weight of these many layers creates enough pressure that the pieces are crushed together to form solid rock again. Sedimentary rock also forms in the same way under the oceans from layers of coral and mollusc shell fragments and is called **biogenic** when it is formed from the remains of once living creatures.

Metamorphic rock is formed when existing rock in the crust is transformed by heating and crushing (high pressure). Because of the heating and crushing, the original rock undergoes chemical and physical changes that make the original minerals change into different minerals. A new kind of rock with different properties is formed.

It is possible to find groundwater in all three types of rock formation. In *Section 3: Groundwater*, you will learn more about how groundwater is stored in rocks and how we get it out of the ground so that we can use it.

> Look down at your feet and imagine drilling a deep hole right down into the ground. What would you find? Would someone standing in Nairobi, Kenya find the same materials as you do if they drilled under their feet? What about someone in another part of the world, for example France or Canada?

Pahoehoe lava in Hawaii, USA, forming new igneous rock. Photo by Hawaii Volcano Observatory (DAS).

Colourful layers of sedimentary rock in Makhtesh Ramon, Israel. Photo by Rhododendrites, Own Work, CC BY-SA 4.0 Wikimedia Commons.

Metamorphic rock cliff at Black Canyon of the Gunnison Park, Colorado USA. Photo by National Parks Services, Lisa Lynch.

The Udden-Wentworth grade scale for clastic sediments

Clay particles:	less than 0.004 mm
Silt particles:	0.004–0.06 mm
Fine sand grains:	0.06–0.5 mm
Coarse sand grains:	0.5–2 mm
Granules:	2–4 mm
Pebbles:	4–64 mm
Cobbles:	64–256 mm
Boulders:	more than 256 mm

A photo of the sedimentary conglomerates layer of the Ngwa deposits. Source: Kenfack et al (2011) CC by 4.0.

Sedimentary rocks can tell a story about water in the past

A closer look at sedimentary rocks can tell us about how water was flowing in an area many, many years ago. For example, on a mountainside near Dschang in Northwest Cameroon, geologists from the University of Dschang and the University of Yaoundé conducted a geological study of rocks known as the Ngwa deposits to understand how and when they formed.

First, the geologists figured out that there are five layers between the surface and 11 metres of depth into the ground. You can see the layers in the diagram on page 17. The first is a thin layer of soil in which plants can grow. Below that is a layer of tuff, which is loose igneous rock that was ejected out of the Mount Bambouto volcano more than 5 million years ago! Below that they found a layer of sedimentary sandstone rock which is even older than the tuff. The sandstone is made up of coarse sand grains mixed together with clay particles. Below the sandstone they found a layer of even older sedimentary rock. This older sedimentary rock contains pebbles and cobbles mixed with sand grains - it is called conglomerate rock. Below the conglomerate, they found a layer of igneous rock called trachyte that formed when magma cooled.

These geological layers tell a story about what the environment was like in this area more than 5 million years ago. The trachyte rock is underneath the other four layers, which means that it is the oldest of them all. It formed when volcanic activity brought magma to the surface.

After the magma cooled, sand, pebbles and cobbles were washed down by water from hills and mountains to cover the trachyte rock and create the conglomerate layer. We know that there must have been a lot of fast-moving water at this time because the pebbles and cobbles are heavy and the water must have been powerful to move them. The shape of the pebbles and cobbles tells us that they must have been moved for many kilometres in a powerful river that bashed them around and slowly caused them to become smooth and rounded.

But the sandstone layer above the conglomerate is different. It contains only small sand grains and tiny clay particles. These particles are so small and light that they only settle out of the water when it is moving very slowly or not at all (this process is like the sedimentation step that you will learn about in *Section 4: Water Quality*). The clay in the sandstone layer tells us that over time the landscape changed and a lake or a swamp formed over the land. Slowly, as sedimentation continued, the lake or swamp would have filled up with sand and clay and eventually there would be no space remaining for water to rest in that place.

After the formation of the sandstone, there must have been another volcanic eruption and the tuff layer was formed on top of the sandstone. Geologists have tested this tuff rock and judged that it is at least 5 million years old. Above this old tuff is the soil layer, which formed more recently from a mix of weathered rock particles and organic remains.

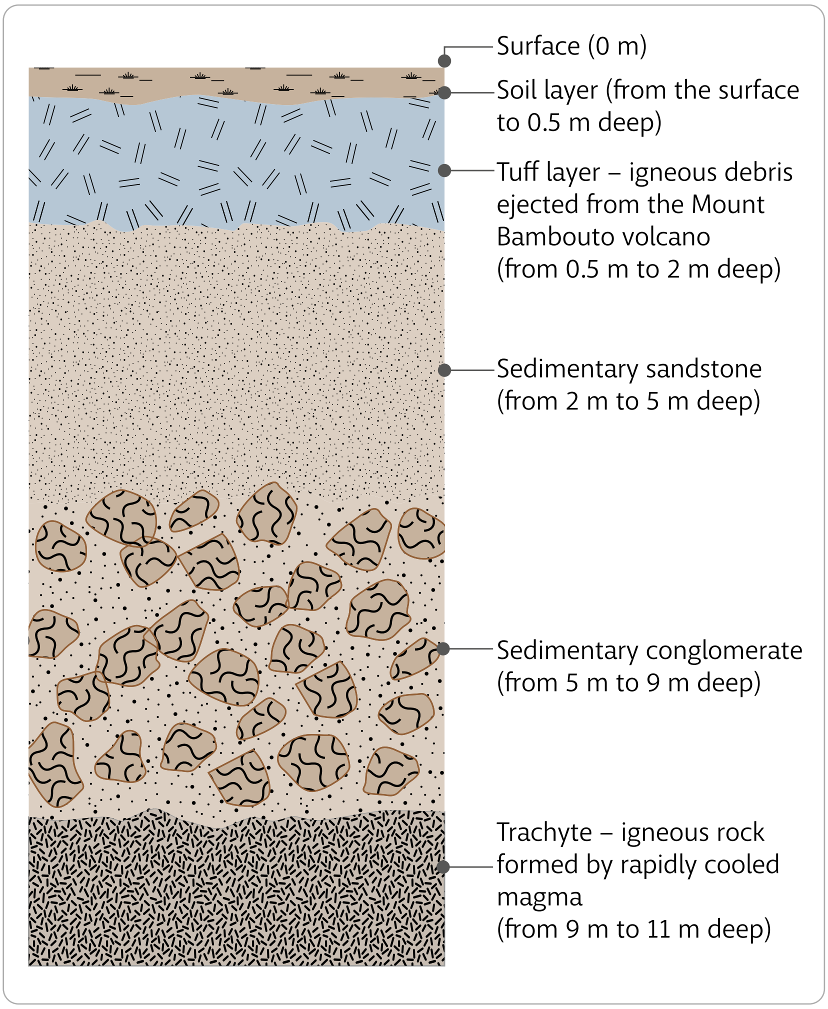


Diagram showing how the rock type changes moving down into the Ngwa deposits. Adapted from Kenfack et al. (2011) CC by 4.0

Water use in mining

Is there a mine in your area? Can you find out what mineral or rock they are extracting and what it is used for? Can you find out how they use water in the mining process?

Using geology to understand water flow in the distant past

On pages 16–17, you read about a study of the geology of the Ngwa volcanic and sedimentary deposits in Northwest Cameroon. You learned that geologists can understand past environments by studying the shapes and sizes of rocks and rock particles. There were three key rules applied in that example:

- Larger rock pieces like pebbles and cobbles require more power to move and are associated with fast-flowing water.
- Rounded, smooth shapes are created when rock pieces are moved by water over long distances.
- Sedimentation of smaller rock particles like sands and clays occurs when water is moving slowly or is still.

Now, can you complete the three tasks below and figure out which environment matches which sample?

Sample Information

Data on sizes of rock pieces:

Size range (mm)	Sediment grade	Sample 1	Sample 2	Sample 3
		Weight percent	Weight percent	Weight percent
more than 256				20
64–256			10	45
4–64			40	20
2–4			30	10
0.5–2			15	5
0.06–0.5		20	5	
0.004–0.06		30		
less than 0.004		50		

Tasks:

1 Fill in the sediment grade label for each size range in the table above.

2 Create a bar graph for each sample to see what the data looks like.

3 Using the data and the descriptions from the geologist's notebook, match the sample with the environments shown in the three pictures on the next page.

Sample 1

Weight %	Clay	Silt	Fine sand	Course sand	Granules	Pebbles	Cobbles	Boulders
100								
90								
80								
70								
60								
50								
40								
30								
20								
10								
0								

Sample 2

Weight %	Clay	Silt	Fine sand	Course sand	Granules	Pebbles	Cobbles	Boulders
100								
90								
80								
70								
60								
50								
40								
30								
20								
10								
0								

Sample 3

Weight %	Clay	Silt	Fine sand	Course sand	Granules	Pebbles	Cobbles	Boulders
100								
90								
80								
70								
60								
50								
40								
30								
20								
10								
0								

Notes on shape of rock pieces from the geologist's notebook:

- **Sample 1** – the geologists have not assessed the shapes yet, so you have no data about this.
- **Sample 2** – the rock pieces are rounded and smooth.
- **Sample 3** – the rock pieces are jagged and sharp.

Which sample matches which environment?

A slope near the top of a mountain where rock is exposed to weathering. Image by brewbooks on Flickr CC BY SA 2.0

The bottom of a lake. Image by Jochem Koole on Flickr CC by 2.0

The bottom of a fast-flowing river. Image by Joe Coyle on Flickr CC BY-NC 2.0

Geology crossword

ACROSS: Clues for horizontal words:

5 The scientific mineral name for ruby (8 letters)

7 A mineral found in granodiorite rock that is formed of only two elements (6 letters)

9 The most common element in the Earth's crust (6 letters)

10 The name for rocks that form from the remains of once living creatures (8 letters)

11 The name for an image captured by a microscope (15 letters)

DOWN: Clues for vertical words:

1 The category of rocks that form directly from cooled magma (7 letters)

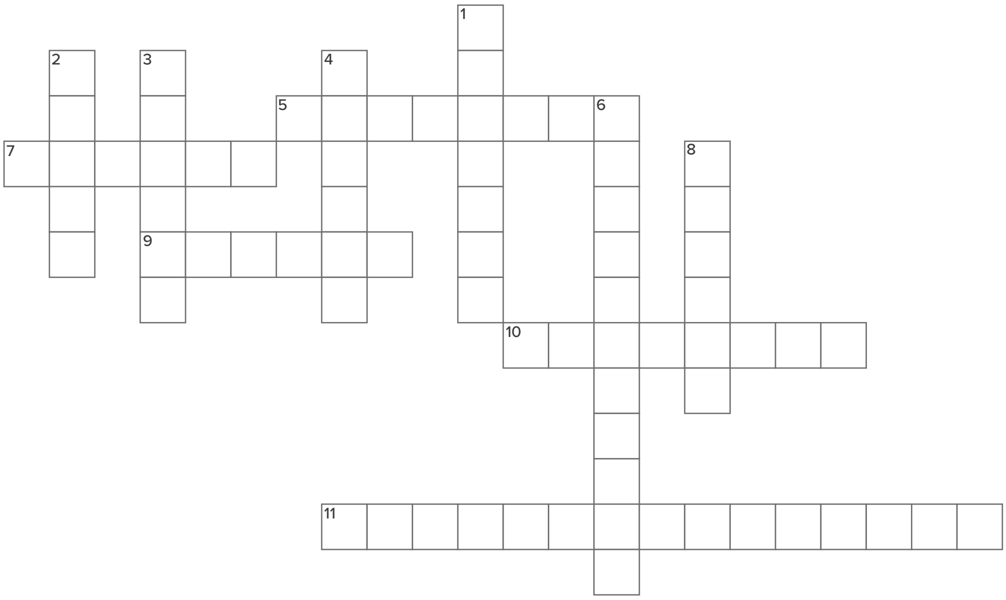
2 The outermost layer of the Earth (5 letters)

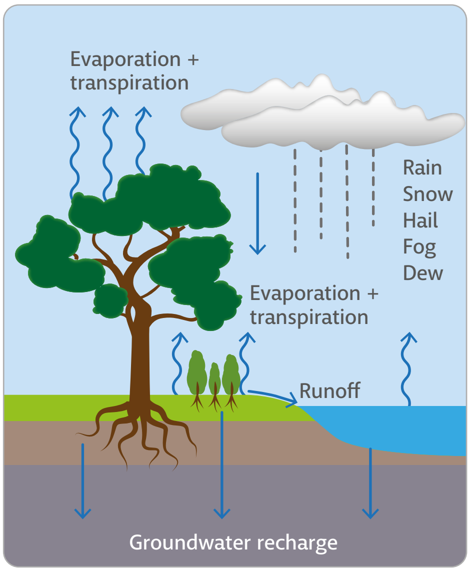
3 The element that forms diamonds (6 letters)

4 The name for rock that is so hot it has become liquid (6 letters)

6 The category of rocks that form from heating and crushing of existing rock (11 letters)

8 A red mineral that is less valuable than ruby (6 letters)





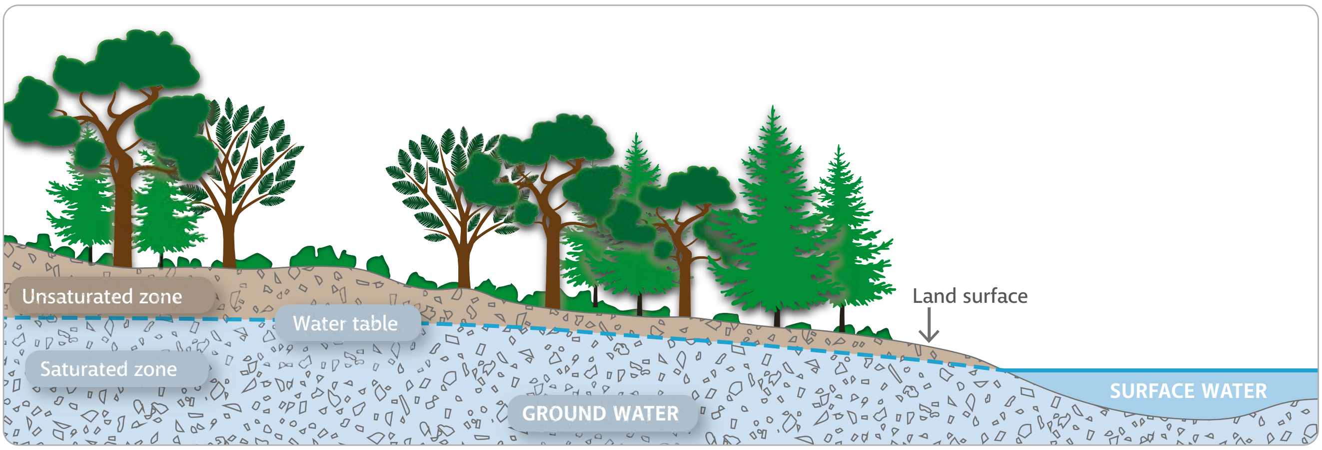
3. Groundwater

How does water get into the ground?

In many places the first layer of the ground is **soil** – a layer of decomposing **organic** material and rock material in which plants can grow. Below the soil layer there are different types of rock materials. The ground can be thought of as two zones – the **unsaturated zone** and the **saturated zone**. The unsaturated zone does contain some water but it also has air in the open spaces between rock materials. Below it, deeper in the ground, is the saturated zone. Saturated means full up – all the open spaces (the pores) are filled with water and the ground is holding as much water as it can. The top of the saturated zone is called the **water table**. This can be thought of as the boundary between the saturated and unsaturated zones.

When precipitation falls on land, some of it goes into the ground. In other words, it infiltrates into the ground. When water infiltrates into the ground, some of it clings to the soil or to roots of plants. This is called **soil moisture** and it can be used by plants to grow. However, not all infiltrated water is used by plants. Some of it flows horizontally through the shallow ground until it ends up in a stream or other surface **waterbody** (this is called **interflow**). Other water flows downwards into the saturated zone below the water table and becomes groundwater (this is called **recharge**). Groundwater is recharged from rainwater and snowmelt and from **seepage** from the bottom of reservoirs, lakes and rivers. Groundwater can also be recharged when water supply systems (e.g. pipes, canals or sewers) leak and when crops are irrigated with excess water.

Cross-section showing unsaturated and saturated zones above and below the water table. Based on USGS 2016.



What is porosity?

Even though it looks completely solid, there is actually a lot of void (empty) space in the ground. Water in the ground is stored in this space, which is made up of a) small voids (called **pore spaces**) between the particles that make up rocks or soil, b) the space created by rock **fractures** (cracks) and c) **solution channels** – the spaces created in carbonate rocks by the dissolving action of underground water. Depending on the geology, some types of ground have more space than others. This is measured using a ratio called **porosity**:

$$\text{porosity} = \frac{\text{volume of void space in rock or sediment}}{\text{total volume of rock or sediment}}$$

Ground that has high porosity can store more water than ground that has low porosity.

Globally, at least 2 billion people depend on groundwater and in rural areas of Africa and Asia it is a particularly important resource for drinking water as well as agriculture and other livelihood uses. It is a very important resource for humans, but only if we can get it out. Removing water from the ground is called **abstraction**. Abstraction is only possible if the water can flow through the ground.

What is permeability?

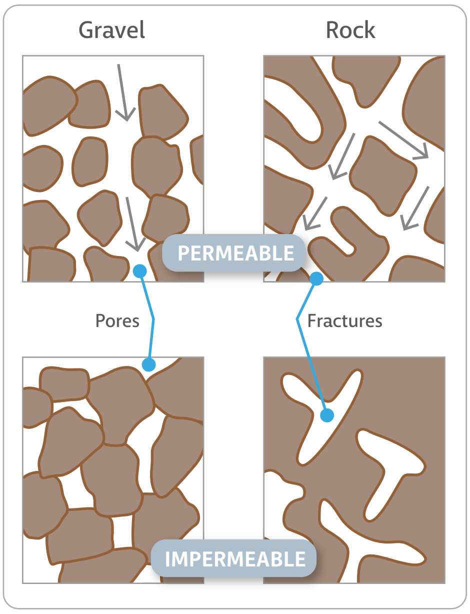
Water can move through the ground when the pore spaces and fractures are connected. If they are connected, water can find a path to flow through the space.

Permeability is a measure of how well the spaces are connected. As an example, some of the rocks which make up the coastal area of East Africa are formed from old coral reef and are very **permeable** – water can flow through them quickly. You can see in the photograph from Kisite Island, Kenya, that it has many small holes and passages.

If a material does not have connected pores, the permeability is low and the water cannot move easily. These materials are said to be impermeable. Geological materials such as clay or shale are made of fine particles and have many small pores, but the pores are not well connected. These types of materials usually stop the flow of groundwater (or slow it down a lot).

Rock formed from coral reef, Kisite Island, Kwale County, Kenya. Photo by www.yakari-travel.de; Flickr; CC BY 2.0.

Sample of shale by Amcyrus2012. Own work, CC BY-SA 4.0 via Wikimedia Commons.



Flowing artesian borehole in Kilimambogo, NE. of Nairobi. Photo by Rotary Clubs of Nairobi, (Kenya), Carlisle, PA and Indianapolis (USA), Edgbaston Convention and Stratford-Upon-Avon, (UK), and Hanau (Germany).

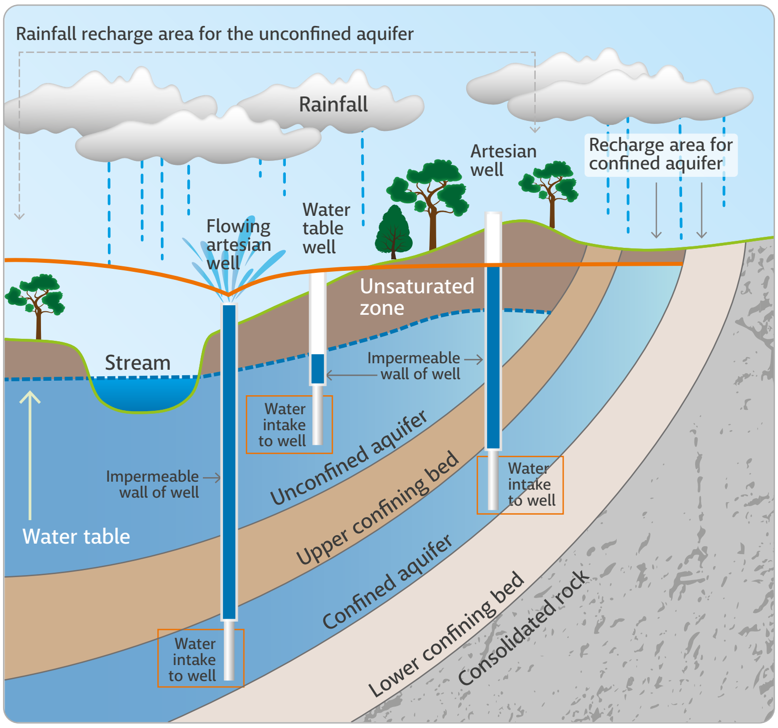
What is an aquifer?

When groundwater in the saturated zone (below the water table) can flow through interconnected spaces we call this zone an aquifer. Aquifers are groundwater resources that people can take water out of. In other words, aquifers are able to yield (provide) water. The layout and properties of different geological materials control how groundwater moves. This means that there are different types of aquifers. The two main types to know about are shown in the figure below.

Unconfined aquifers: The top of an unconfined aquifer is the water table, usually not far below the ground surface. Water at the ground surface infiltrates through the unsaturated zone to recharge the aquifer. The lower boundary of the aquifer is a confining layer of less permeable material (an **aquitard** or **aquiclude**). An aquitard is a layer of material that slows the flow of water. An aquiclude is a completely impermeable layer that stops water movement. The water in an unconfined aquifer is at atmospheric pressure so to get it to the surface it must be pumped out or pulled out (for example with a handpump or a bucket in an open well).

Representation of unconfined and confined aquifers. Although the aquifers look like big caves full of water, remember that they are full of sediment and rock and the water is stored in the spaces between this material. Adapted from the United States National Groundwater Association.

Potentiometric surface

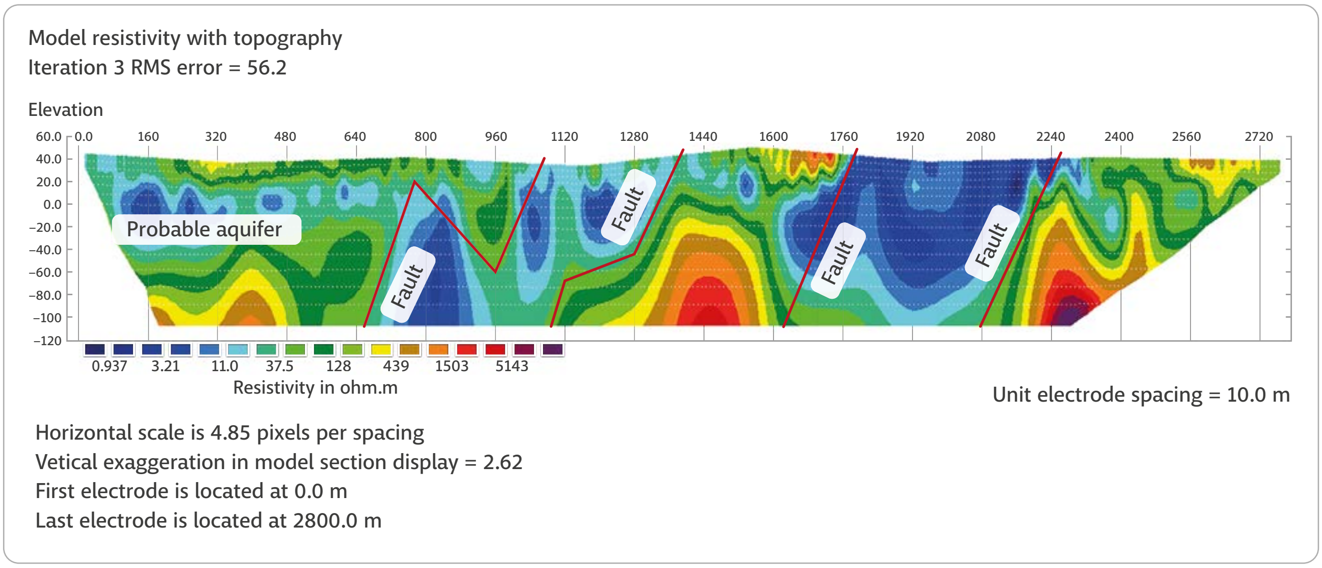


Confined aquifers: Both the upper and lower boundaries of confined aquifers are rock layers of low or no permeability (i.e. they form an aquitard or aquiclude). These are usually deeper than unconfined aquifers. In a confined aquifer, the water is under pressure from the rocks above and/or from the water flowing into it from a recharge zone. If a **borehole** is drilled into a confined aquifer, water will rise inside the borehole due to the pressure on it, and it may even flow out at the top. A borehole drilled into a pressurized aquifer is called “artesian”. The name artesian comes from the first recorded example of a naturally flowing well which was drilled by monks in the province of Artois in France in 1126.

> See the ‘flowing artesian well’ in the figure and photo on page 24? Water is coming out of it without pumping. Can you explain why in your own words?

As you learned in *Section 1: The water cycle*, groundwater is part of the water cycle. Aquifers are recharged by infiltration from the surface, and groundwater flows into waterbodies and oceans. It is important to understand that the way that water flows into, within, and out of the ground in any place can change over time. Changes to the climate affect groundwater recharge patterns. Geological processes, which slowly change landscapes through the creation of new rock and the **weathering** of old rock, also impact groundwater and can even cause some water to become confined in the ground for a very long time. **Paleowater** is the term used for groundwater that has remained in an aquifer for thousands or millions of years.

Example of results from a geophysical transect using electrical methods (Gro for GooD project, coastal Kenya). The labels show the geophysicists’ initial interpretation of the results. The identification of faults (breaks in the rocks where the rocks on either side have moved in relation to each other) is important because fissures, cracks and faults in the rock affect how groundwater will flow through it.



Drill rig in coastal Kenya. Photo by Mike Lane.

How do people access groundwater?

Shallow groundwater can be accessed by digging a well that goes deeper than the water table (into the aquifer/saturated zone) and then drawing water out. Groundwater can also be accessed by drilling a borehole down into the aquifer and pumping the water out. There are many kinds of pumps including electric pumps, solar pumps, diesel pumps, and handpumps. The Afridev is the most common handpump in all of Africa.

In what ways do you think handpumps are better than solar pumps? In what ways are solar pumps better than handpumps?

How is groundwater detected and assessed?

Hydrogeology is the study of groundwater and the geological and non-geological materials that it interacts with. Hydrogeologists study aquifers to understand how they can be used and sustainably managed. They use data to predict what will happen to aquifers when water is abstracted or when changes to the climate reduce or increase rates of groundwater recharge. Knowing where water goes and how fast it moves underground can also help prevent or limit groundwater contamination.

It is challenging to detect groundwater because you cannot see through the ground. Hydrogeologists can use climate and geological data to assess if groundwater is likely to be found in a particular area. They also use "geophysical methods" to measure physical properties of rocks below the surface and map out where water will be found and how it will move underground. Geophysical methods help us understand the geology of an area better. Understanding the geology helps us know how much water may be stored. When the geology indicates that there may be a lot of groundwater, boreholes can be used for further studies to assess how much can be abstracted for human use.

Boreholes can also be used to take samples to assess water quality. Hydrogeologists do a lot of work to understand the chemical and biological quality of groundwater. You will learn about water quality in *Section 4*.

Is groundwater a sustainable resource?

Whether groundwater can be used in a **sustainable** way depends on how much is being used and how quickly it is being recharged by infiltrating water. If recharge is reliable and the amount abstracted is less than the amount recharged, we can treat the groundwater as a **renewable** resource. However, if abstraction and outflow is greater than recharge, this is called **over-abstraction** and the aquifer will eventually be pumped dry.

Groundwater that is being recharged slowly or not at all should be managed as a **non-renewable resource** – once it is gone, it is gone. In these situations, water managers should be careful about how much water is being used and for what purposes, they should work out ways to conserve water and minimise wastage, they should consider options for building infrastructure to increase recharge to the aquifer, and they should be planning for what to do in the future.

How can you grow crops without rain?

In some dry areas of the world, even though there is hardly any groundwater recharge from rainfall, water can still be pumped up from underground and used for growing crops. For example, large groundwater reserves under the Sahara Desert in North Africa are used to grow crops in huge circular fields using a technique called pivot irrigation, as seen in the picture.

The water in the Saharan aquifer is paleowater – water that has been trapped deep in the ground for a million years - it infiltrated into the ground when the climate in northern Africa was very different and there was a lot of precipitation. As the aquifers in this area are not linked to the oceans, or to rivers or lakes, this groundwater has been sitting there all this time.

In the case of the Sahara Desert in North Africa, a recent study has shown that the massive aquifer beneath the desert is actually being recharged: rainwater and run-off bring an average of 1.4 km^3 of water into the aquifer per year. However, water is being abstracted from the aquifer at a rate of 2.75 km^3 per year for use in crop irrigation, industry, tourism and households.

> Based on the rates of abstraction and recharge in the Sahara given above, is the groundwater in the aquifer being used sustainably?

You could say that using renewable groundwater is like spending some of the money you earn every month, whereas over-abstraction is like using up your savings until eventually you have none left. Can you think of another analogy that could be used to explain sustainable versus unsustainable rates of groundwater abstraction?

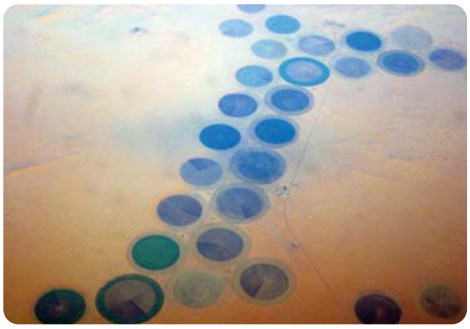


Photo taken from an aeroplane of pivot irrigation in the Sahara desert Future Atlas.com, Michele Walfred, University of Delaware, USA. CC BY 2.0.

Close-up photo of a pivot irrigator in use. Photo by Patrick Thomson.

Groundwater where I live

Are there boreholes, wells or handpumps accessing groundwater near to your school? Ask your teacher if you can arrange one of the following activities to find out more about a groundwater source:

- Arrange to interview some of the people using the groundwater source – What do they use the water for? How often do they visit to collect water? Are there any problems with the water source? What other sources of water do they use?
- Can you find out who drilled the borehole or well and/or who installed the handpump? Who looks after the water supply and keeps it in good condition?

Infiltration experiment

If you dig into the ground where you live, what do you find? Soil? Sand? Pieces of gravel? Rock? Does this vary depending on where you dig? This experiment aims to show how the rate of infiltration (how fast rainwater soaks into the ground) varies depending on the material at the surface. It will also demonstrate the porosity and permeability of different materials.

Materials

- Gravel
- Sand
- Soil (or a different type of sand if soil is not available)
- 3 plastic bottles
- Measuring jug or bottle
- Stopwatch
- Scissors/knife
- String or wire
- Small circle of fine cloth or window screen
- Tape
- Water

Method

1 Make 4 holes at the base of each plastic bottle 3 cm from the base.

2 Cut off the bottom of the bottle 1-2 cm from the base.

3 Thread 4 pieces of string through the holes so that the bottles can be suspended upside down.

4 Take the lid off the bottles and tape a piece of fine cloth over the opening.

5 Hang the bottles up in a row.

6 Fill the first with soil, the second with sand, the third with pebbles or gravel.

7 Draw a picture of the set up. Can you see any pores in the material?

8 Make a prediction – which material do you think will allow fastest infiltration of water?

9 Place the empty measuring jug underneath one of the bottles and get your stopwatch ready.

10 One person starts the timer whilst another person pours 250ml of water into the top of the first bottle (slowly so it doesn't overflow).

11 Observe and record the volume of water in the measuring jug after 30 seconds, 1 minute, 5 minutes, 10 minutes, 30 mins.

12 Repeat timed experiment for the other bottles (If in groups, compare your results with the groups with other materials in the bottles). What did you observe? Make a graph of your results.

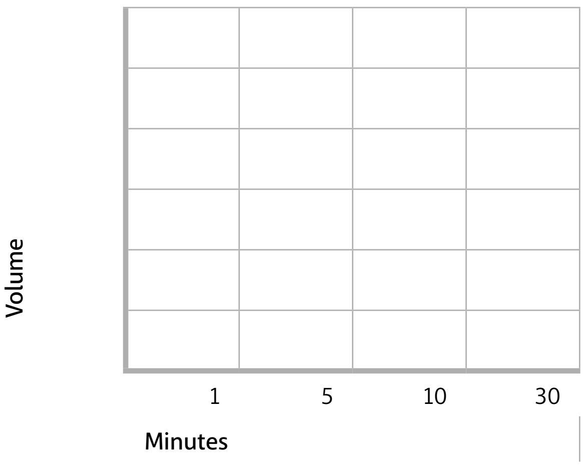
Infiltration experiment worksheet

Draw a picture or diagram to show how the experiment is set up:	
Make a prediction: Which material do you think will have the fastest infiltration rate and why?	

Soil		Sand		Gravel	
Time (mins)	Volume (ml)	Time (mins)	Volume (ml)	Time (mins)	Volume (ml)
1		1		1	
5		5		5	
10		10		10	
30		30		30	

Graph

Plot soil, sand and gravel data in different colours. The slope of the graph shows the infiltration rate.



Conclusion

Which material allows water to infiltrate the fastest?	

Saturation experiment

After 30 minutes put the lids back on each of the bottles. Had all 250ml been filtered through the bottle into the measuring jug?

Fill the measuring jug with 1 litre of water and pour slowly into each bottle, slow enough so that it soaks in and doesn't overflow over the sides straight away. What is the maximum volume each bottle can hold?

Saturation experiment worksheet

	Soil	Sand	Gravel
Volume left in bottle after 30 mins (ml) [A] (250ml minus volume recorded in previous table)			
Volume poured into the bottle before it cannot hold any more (ml) [B] (1000ml minus what is left in measuring jug)			
Maximum saturated volume (A+B)			
Which material holds the most water?			

Using your results, how would you rank the different materials in terms of porosity and permeability? • Soil • Gravel • Sand	↑ Most porous Least porous	Most permeable ↑ Least permeable

If you wanted to make an impermeable layer in one of the bottles, what material could you use?	

Groundwater crossword

Test your groundwater knowledge by using the clues to fill in this crossword puzzle.

ACROSS: Clues for horizontal words:

2 The zone between the land surface and the water table where pore space contains both water and air (15 letters – 11, 4)

4 A break or crack in a rock (8 letters)

5 The study of groundwater and the geological and non-geological materials that it interacts with (12 letters)

6 Groundwater that has been stored in an aquifer for thousands of years (10 letters)

7 What we call material that has connected void spaces so water can flow within it (9 letters)

8 A layer of geological material that is impermeable; it stops the flow of water (9 letters)

10 What we call material that is holding as much water as possible (9 letters)

11 A deep, narrow hole made in the ground, usually to locate water or oil (8 letters)

12 Movement of water a) into the ground from a surface waterbody or b) out of the ground into the ocean or onto land (7 letters)

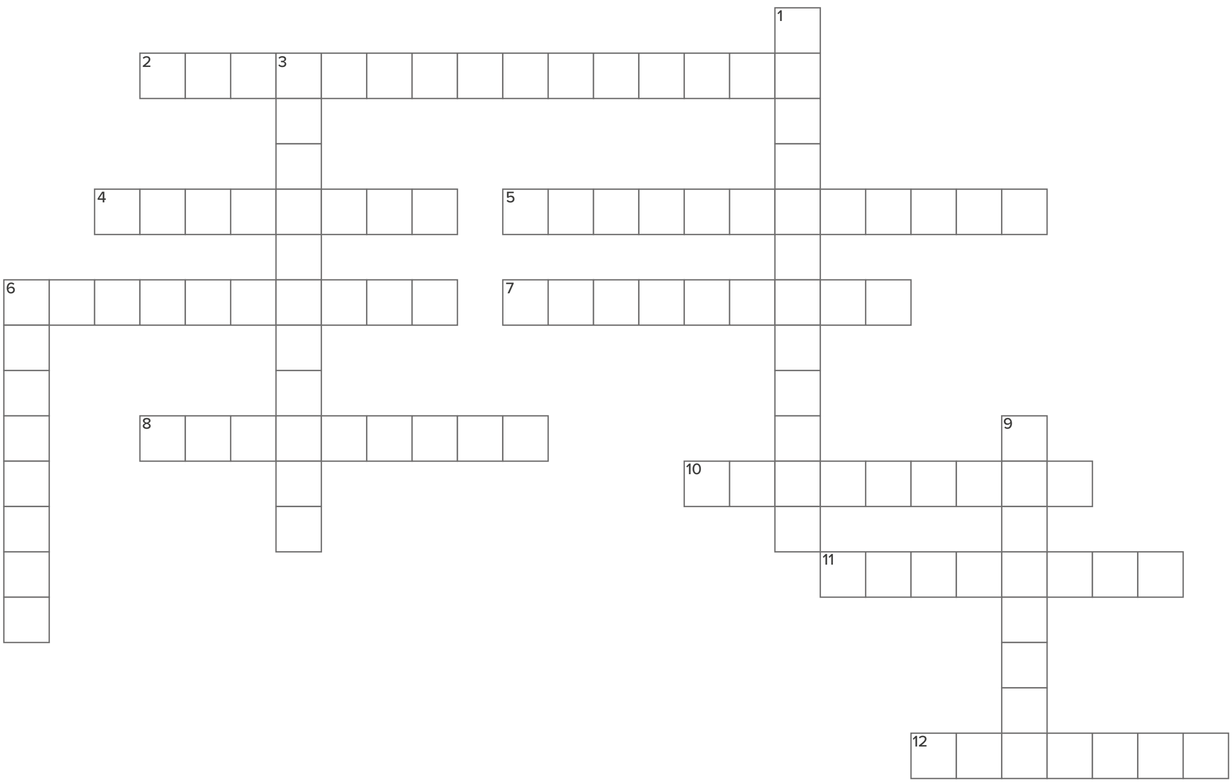
DOWN: Clues for vertical words:

1 A measure of the connectivity of void spaces in the ground (12 letters)

3 The process of taking water out of the ground temporarily or for permanent use (11 letters)

6 The ratio of the volume of void spaces in a rock/sediment to the total volume of the rock/sediment (8 letters)

9 Water that is added to an aquifer (e.g. when rain infiltrates into the ground) (8 letters)



Photos licensed from Thinkstock.

4. Water quality

Water is a natural habitat for many living things and it is a powerful **solvent**, so as it moves through the hydrological cycle it picks up and carries many things with it. Because of this, **water quality** will naturally be different in different places and at different times of year.

When thinking about water quality, there are three main considerations:

1. **Microbiology** – bacteria, viruses, protozoa, and worms
2. Chemistry – dissolved metals and other elements and chemicals
3. Sensory – temperature, colour, smell, taste, **turbidity**

Sensory quality refers to the characteristics of water that can be judged by the senses – sight, taste, smell, and touch. But many microbiological and chemical water quality characteristics are not observable unless the water is tested in a laboratory or with a field-testing kit. These tests are created by chemistry and microbiology scientists and they make it possible to figure out what is in the water. Usually you can only test for one thing at a time, so many tests are needed to fully describe understand the total water quality.

Water quality standards

When water quality is tested, the results can be compared to water quality standards. Water quality standards tell you the limit of how many biological organisms or how much of a chemical substance can be in an amount of water before it becomes unsafe. They are expressed as measures of **concentration**, which is a scientific term that means 'the relative amount of a substance contained in a particular volume of solution, mixture, or space.'

For example, fluoride is an element that naturally occurs in some types of rocks and can be dissolved in groundwater. Consuming a small amount of fluoride is good for people – it can help with protecting teeth from decay. But consuming too much fluoride is bad for people – too much fluoride can cause tooth decay and weaknesses in bones. The World Health Organisation advises that drinking water should not contain more than 1.5 milligrams of fluoride per litre of water, but concentrations of less than 1.5 mg/L of fluoride can be good.

For other substances, like the bacteria *Escherichia coli*, there is no good amount. The World Health Organisation advises that drinking water should have zero *Escherichia coli* bacteria per 100 mL (about the size of a small glass of water). This is because the presence of *Escherichia coli* in water may indicate that the water has been contaminated with human or animal faeces, and therefore it may contain **pathogens** that cause diarrhoea and other health problems.

Many countries base their drinking water standards on guidance from the World Health Organisation. In addition to drinking water standards, many countries also have environmental water quality standards and recreational water quality standards. When water quality is tested, the results can be compared to these standards to see if the water is safe for drinking, swimming, bathing, and for wildlife and healthy ecosystems.

What do you think would be a good way to decide what concentration a water quality standard should be set at?

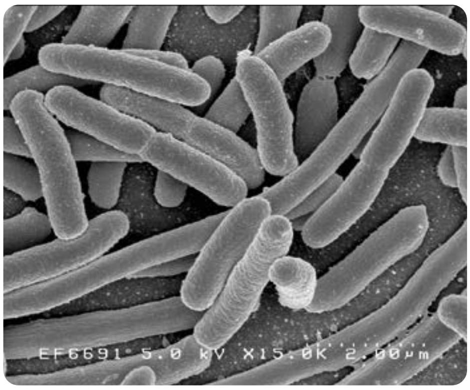


Image of *Escherichia coli* bacteria taken by a scanning electron microscope, which is a special type of microscope that produces images by scanning the surface of a sample with a beam of electrons. The bacteria are very tiny (about 2 µm long) so we cannot see them unless we use a microscope that allows us to magnify their size. Photo by NIAID. CC BY 2.0.

Dark siltstone with minerals containing iron and other elements that can be dissolved in groundwater. The rusty red colour is caused by the iron being exposed to the air. Iron is not harmful to health, but when large amounts of iron are dissolved in groundwater it can become coloured and have a metallic taste. Photo by Saskia Nowicki.

A puddle of water with oil pollution. Photo by MPCA Photos. CC BY-NC 2.0.

Contamination and pollution

Most of the things that are dissolved or living in water are harmless or even beneficial. However, it is possible for water to be polluted by human activities or to be naturally contaminated with substances that can cause illness and/or make the water taste bad.

Natural contamination: Water can contain microbiological pathogens that are spread by wildlife. This is more common for surface water than for groundwater because wildlife are more likely to make contact with surface water. Groundwater is naturally better protected from pathogens, but that doesn't mean it is always safe. Water can dissolve elements from rocks that are harmful to human health. For example, an element called 'arsenic' is common in rocks in some areas and high levels of arsenic can cause diseases in humans. Arsenic is tasteless, odourless, and colourless, so to confirm if it is in an aquifer the water must be tested. Water can also dissolve other elements from rocks that can make it taste salty. This is one reason why groundwater can be naturally salty, even when it is far away from the ocean.

Pollution from human activities: Water can be polluted by humans in many ways. Some examples include:

- Improper management of **wastewater** and solid waste (including open defecation, livestock waste, building latrines too close to water sources, or inadequate sewage treatment)
- Improper use of fertilizers and pesticides in agriculture
- Insufficient management of wastewater outflows from industrial activities
- Swimming and bathing in water sources

In cases when natural contamination is a problem, water will have to be treated or sourced from a different location. Water treatment is also often needed to manage water quality impacts from human activities.

Water treatment

Not all **pollutants** are visible, so even though water may look clear it could still be unsafe to drink. The best way to have safe drinking water is to use a multi-barrier approach. This is the approach that is recommended by the World Health Organisation and it involves five different steps:

- Source protection
- Sedimentation
- Filtration
- Disinfection
- Safe storage

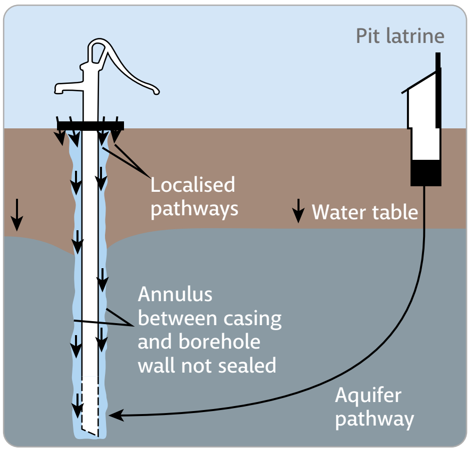
The first step is to protect the water source from being polluted. After water is protected as well as possible, the next steps are **sedimentation**, **filtration** and **disinfection**. These are all types of treatment. This treatment can be done at a very big scale. For example, the picture on the right shows a water treatment facility in Spain that can treat 200,000 cubic metres of water in a day (that is 10 million 20 litre jerry cans!). In places that do not have centralised treatment facilities, and most **rural** places do not have them, the same three treatment steps can be used at the household level to make water safer.

The Llobregat water treatment facility in Barcelona, Spain. Photo by Saskia Nowicki.

> Is there a water treatment facility in the city you are in or near to? Can you find out what processes they use to treat the water? Can you find out what volume of water they treat? How many people use this water?

1 Source protection

Protecting water can lead to improved water quality and health. Protecting water means keeping pollutants away from it. Usually, **surface water** is more difficult to protect than groundwater because it is more difficult to prevent humans and animals (and their waste!) coming in contact with the water when it is open to the air. Protecting surface water as much as possible can help to improve water quality, but usually treatment will still be needed to make the water safe to drink.



Two pathways to groundwater pollution. Note: The 'casing' is the pipe that is installed into the borehole which has holes at the bottom to let the water in; the 'annulus' is a ring-shaped hole that forms between the sides of the drilled hole and the pipe/casing. The annulus is supposed to be blocked up with special material to stop water from travelling down it, but sometimes this is not done properly (Lawrence et al. 2001).

Remember that pollution in rivers will flow downstream, so if possible, it is better to collect water upstream of where pollution is happening. For example, if there is an area of the river where people usually go to wash or animals usually go to drink, you should collect water upstream from that place.

Groundwater is often cleaner and less accessible than surface water, and water is naturally filtered through layers of ground material before it enters aquifers, this process can remove some pollutants. However, aquifers are vulnerable to pollution when:

- The water table is close to the surface. For example, when you can see the water in an open well it is close to the surface
- The ground above the aquifer is permeable. The more permeable the ground is, the more easily pollutants can flow into the aquifer

Different pathways to groundwater pollution

In many parts of Sub-Saharan Africa, people rely on shallow groundwater pumped out by handpumps from unconfined aquifers. The ground is permeable above unconfined aquifers, which means that the groundwater can be polluted from latrines and other waste sources on the surface (for example animal faeces inside livestock pens). When pollutants are washed down through the ground into an aquifer, the pollution has arrived in the groundwater through the '**aquifer pathway**'. Pollution of groundwater can also come from '**localised pathways**'. This is when pollutants enter the water through wells/boreholes themselves (or the ground immediately surrounding them). This happens if wells/boreholes are not well protected or properly constructed. The figure on the left shows an aquifer pathway by which pollution has entered to groundwater from a latrine as well as localised pathways directly around the borehole.

What factors might affect how far away a pit latrine needs to be from a borehole to avoid the risk of pollution?

Have you heard of composting toilets? Would they be useful in your area?

Protecting groundwater from pollution

Protecting groundwater requires consideration of both aquifer and localised pathways. To be effective, water protection requires **stakeholders** to work together. The first thing to do is identify all the possible sources of pollution in the area and then try to keep the pollutants away from the water. These are some important steps that communities can take:

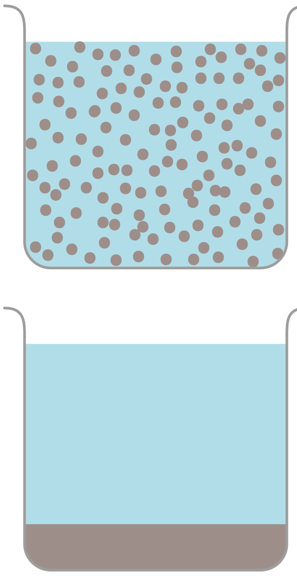
- Keep the area around the water source as clean as possible (remove garbage, faeces and other types of pollutants so that they cannot be washed into the well/borehole)
- Build latrines away from and downhill of water sources
- Use latrines and avoid open defecation especially near water sources
- Build fences to prevent animals from going near water sources
- Build animal pens away from water sources
- Build good drainage channels around taps and pumps so that water does not form pools in which pathogens can collect and then infiltrate into the groundwater
- Use concrete to cover the area around handpumps and wells so that surface water cannot flow directly into the well through the surrounding ground
- If a pump is not available and it is necessary to use buckets to collect water, keep the buckets and rope as clean as possible

It is important to remember that this is an ongoing task. To protect water, stakeholders need to regularly inspect the area around water sources for potential hazards and take actions to keep pollutants out of the water. The most common and harmful pollutant is often human and animal faeces.

2 Sedimentation

Even if you have done your best to protect water, it may still contain contaminants that could make people sick. You can do sedimentation for another layer of safety. This is a very simple step; it just takes time. Sedimentation happens when you let water sit in a container and the particles that are suspended (floating) in the water slowly fall/settle out to the bottom because they are heavier than the water. Large particles will settle to the bottom more quickly, small particles will take more time.

A rural water kiosk with a fence protecting the borehole pump house and kiosk. Photo by Saskia Nowicki.



An example of a ceramic bucket filter being tested by a school water club in Kwale County, Kenya. In this example the water slowly passes through the ceramic layer that has been inserted inside the bucket. This ceramic has been specially treated to make it more effective at removing pathogens. When the water passes through the ceramic it collects at the bottom of the plastic bucked and can be poured out using the small tap. Photo by Kingwede School Water Club.

It is possible to add chemicals to the water to make the particles group together into clumps. The clumps are heavier so they settle out faster. These chemicals are used in large water treatment facilities and sometimes households will also use them in small amounts. Alum (hydrated potassium aluminium sulphate) or crushed seeds from the Moringa plant are widely available and can be used to speed up the sedimentation process. In the activities section you will learn how to do this.

If you do not have access to alum or Moringa, you can still let sedimentation happen – it will just take longer. Put the water in a clean container, cover it so that no additional pollutants can enter, and wait. After some time, the water will become clearer and you can take it out of the container. Be careful not to disturb the particles (sediment) at the bottom of the container otherwise it will mix back into the water and the water will become turbid again.

When water has high turbidity it is good to do sedimentation before filtering or using disinfection products because the filter will then last longer and the disinfection will work more effectively.

3 Filtration

After sedimentation, the next step is filtration to remove contaminants that are too small and light to settle out during sedimentation. When water does not have high turbidity, you can skip directly to filtration. Filtration is a physical process that involves passing water through a filter – a material that catches contaminants, which are larger than water particles, and holds them back while clean water drains through. Some filters are also designed to grow a biological layer that kills or inactivates pathogens and makes their removal more effective. There are many kinds of filters. Some work better than others and different filters can remove different types of pollutants. Ceramic, for example, is often used as a filter material.

Other common types of filters are **membranes** and sand. Membranes are flexible sheet-like material that acts as a boundary to block pollutants from passing through. There are many kinds of membranes but they are often expensive and can be difficult to acquire. Sand is a less technical solution and it can be effective. Sand filtration can be done to treat water for a whole community if the community builds a good slow sand filtration system. Such a system is made up of different parts including water storage tanks, an aerator, pre filters, and slow sand filters.

It is important to remember that all filters will eventually get clogged up by the matter that they have removed from the water. When this happens, they must either be cleaned or replaced. Different filters can last for different lengths of time and have different procedures for cleaning / replacing.

UV Radiation using clear plastic bottles. Photo by SODIS Eawag, CC BY 3.0, Wikimedia Commons.

4 Disinfection

After filtration, there is another important treatment step to make water safe for drinking: It must be disinfected. Disinfection will kill pathogens that remain in the water after the first two treatment steps. There are different ways to disinfect but the most common are:

- **Chlorine** – The effectiveness of chlorine disinfection is impacted by the chemistry and temperature of the water, but guidelines are available to know how much chlorine should be used for different volumes of water. If chlorine tablets, liquid, or powder are purchased for treating drinking-water at home or at school, the package should come with instructions for how much to add to a particular volume of water.
- **Boiling** – Boiling will kill pathogens regardless of the chemistry of the water. Boiling should be done for at least 1 to 3 minutes to be safe. Of course, boiling requires fuel to heat up the water and this is sometimes difficult or expensive to obtain.
- **Ultraviolet radiation exposure** – Ultraviolet (UV) radiation comes from the sun. Water that is left in the direct sun can be disinfected by UV radiation. Water does not have to reach boiling temperatures (because in this case it is not the temperature that is killing the pathogens) but it needs to be exposed to the sun in a clear and shallow container. Some companies make special containers for this purpose, but it is also possible to use plastic water bottles (see picture on this page). If using this method, it is particularly important to do sedimentation and filtration first because otherwise pathogens can 'hide' behind turbidity in the water to survive the UV exposure.

When relying on UV exposure to disinfect water, it is important to leave the water in the sun for long enough. The length of time that is needed depends on how strong the sun is. There are devices that measure the strength of UV radiation and tell you when the water has been exposed for long enough (e.g., the WADI device manufactured by a company called Heloiz). If you do not have access to a device like this, the general guidance is that when the sun is strong and there are no clouds, the water should be exposed for one day (including the hottest hours in the middle of the day). When the sun is not strong and it may be partly cloudy, the water should be exposed for two days. If it is raining or very cloudy, this method of disinfection should not be used.

- **Solar distillation** – Another disinfection method that uses energy from the sun is solar distillation. Distillation purifies water through evaporation and condensation. First water is heated using solar energy until it evaporates. The water vapour is then captured in a separate container and cooled down so that it condenses back to liquid form. When water evaporates, it leaves behind anything that it was carrying so all pollutants are left behind. This method can even remove salt from saltwater. Of course, you must get rid of what is left behind (which is called 'residual brine'). If there are pollutants in the brine that may be harmful to the environment, you must be careful how you manage it.

What are the advantages and challenges of each disinfection method? Which do you think is the best method and why?

5 Safe storage

After all the work of protection, sedimentation, filtering and disinfection has been done, the final step is to store the water safely. It is possible for water to be polluted again after it has been cleaned – safe storage makes sure this does not happen. Keeping clean water stored safely means storing it away from possible sources of pollution. The most important thing is to keep animals and people (including hands and feet!) out of the water. Here are some tips:

- Keep water in a clean and covered container (it should be a special container that is only for treated water)
- Remove water from the container using a tap or by pouring it through a narrow opening in a way that will not let anything get into the container and prevents hands from touching the water
- Make sure the container has a stable base so it does not tip over and if possible, keep it elevated off the ground
- When the container is empty of water, clean it carefully with soap or diluted bleach, and rinse it well with clean water

It is best to drink water soon after it has been treated. The longer it is left in storage the more likely it will become dirty again.

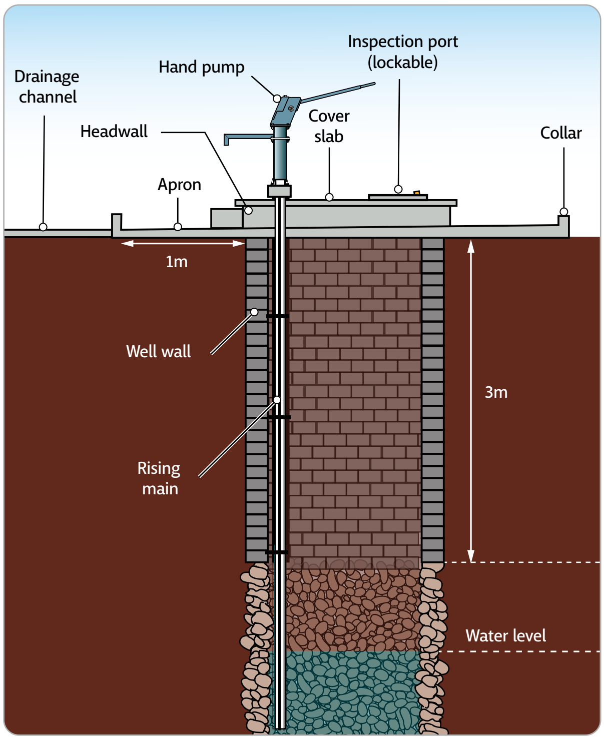
How is water stored at your home or school? Could this be improved based on the information above?

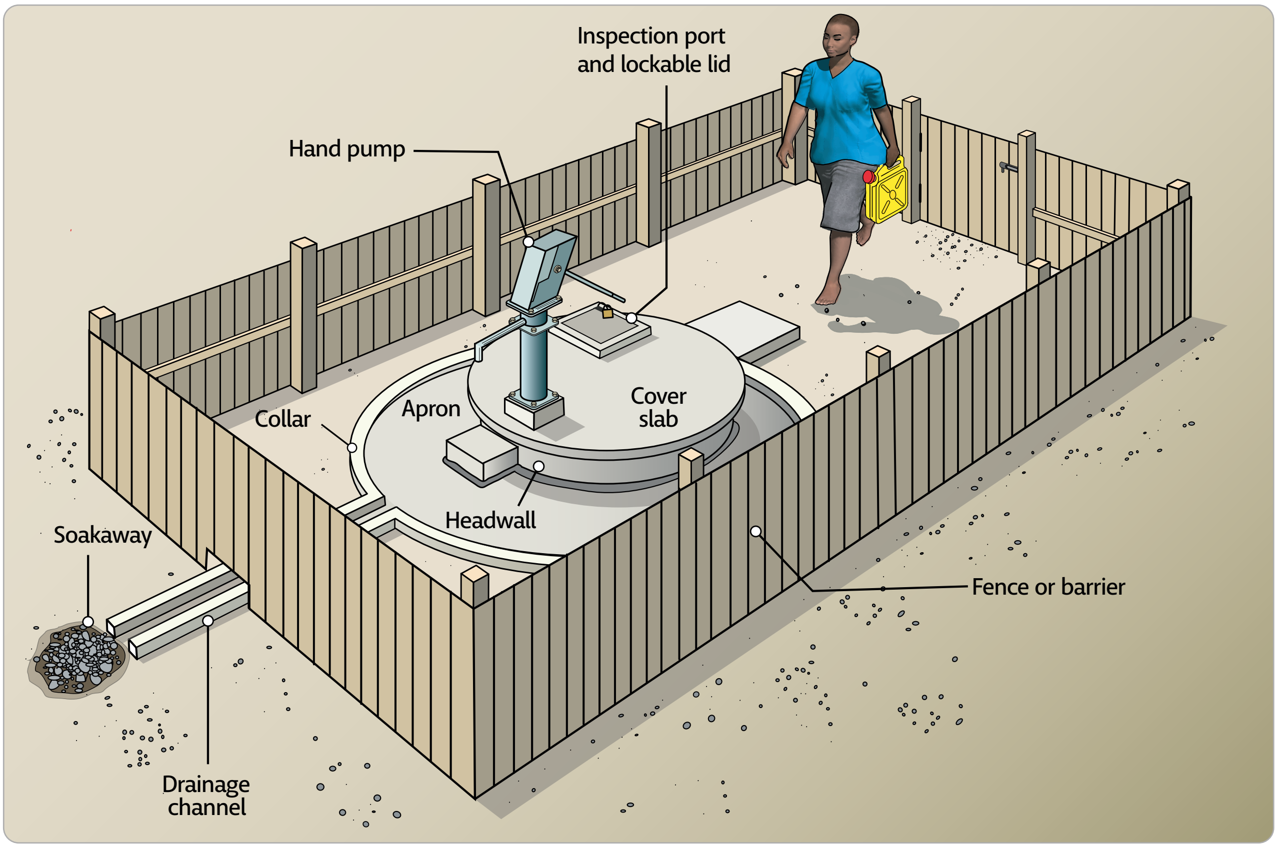
School water storage tanks in Kitui County, Kenya. Photo by Saskia Nowicki.

Doing a sanitary inspection of a water supply

In many rural areas, people get drinking water from handpumps that are installed on boreholes or dug wells. The pictures on this page show the recommended design for dug wells with handpumps to make sure that they are protected from pollution. But often conditions in real life do not match with this recommended design.

The World Health Organisation (WHO) provides guidelines for examining water supplies to figure out what hazards need to be managed to protect the water quality. The first step is conducting a "sanitary inspection". **Sanitary** means a clean environment that is free from pollution, especially faecal waste that can spread microbiological pathogens. Sanitary inspection is an activity where you examine a water supply and answer questions about what pollution hazards you have observed.



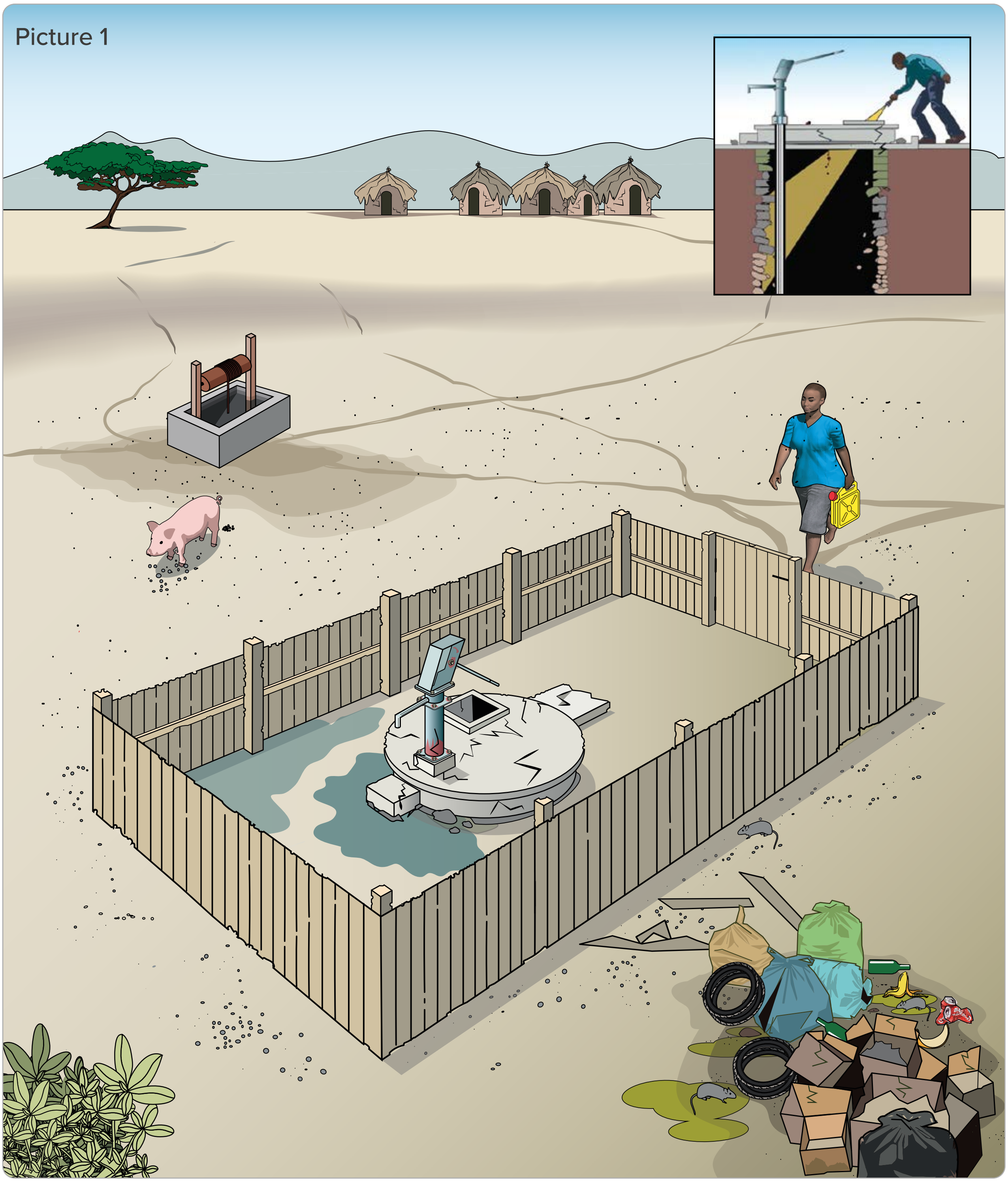


Part 1. Conducting a sanitary inspection.

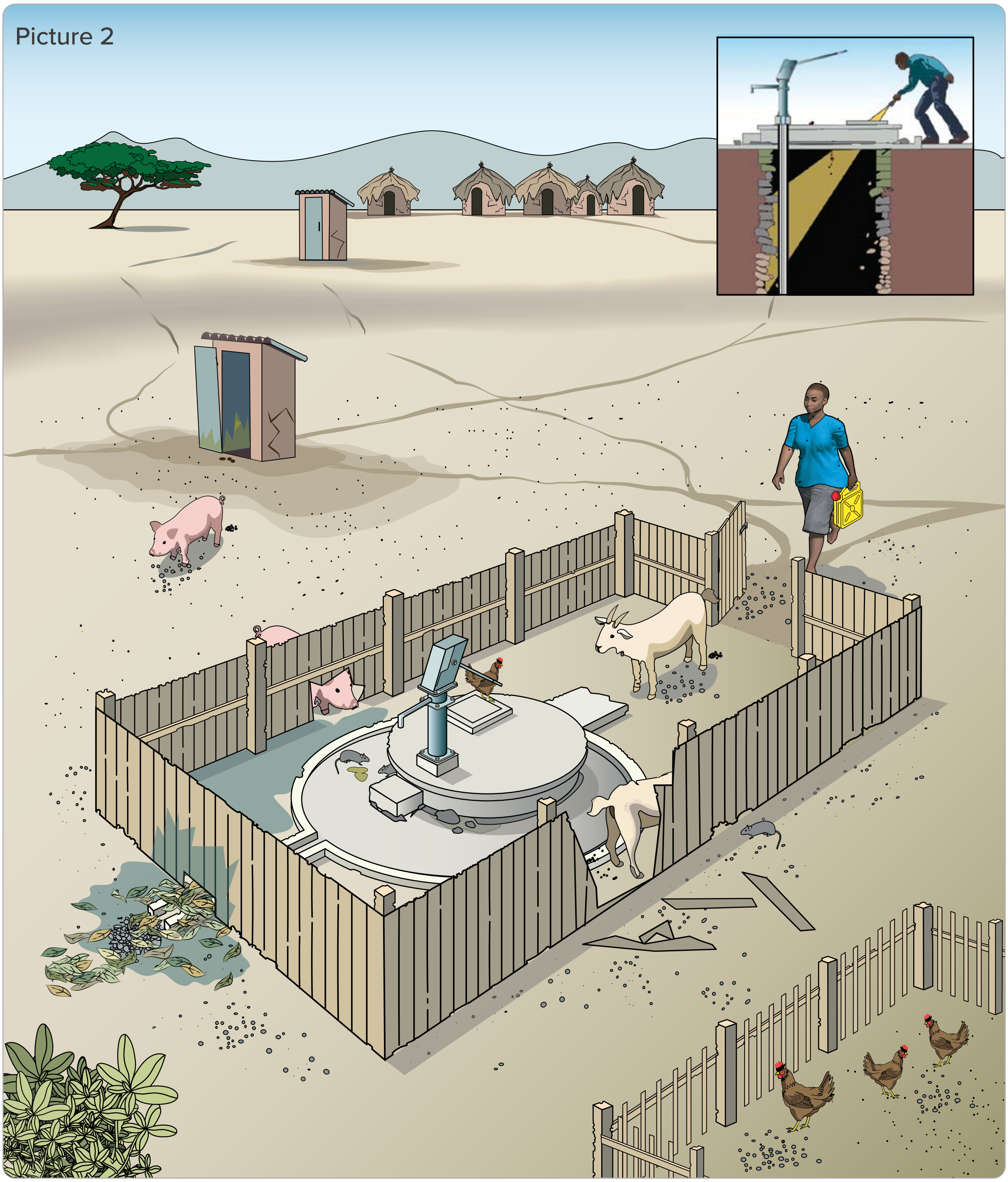
Look at the two pictures on pages 43 and 44, each shows a handpump that is installed on a covered dug well in a rural area. In each picture there are some hazards that could be causing pollution of the water in the well.

For each picture, answer yes or no to the WHO sanitary inspection questions and then count how many times you answered yes.

Picture 1



Picture 2



WHO Sanitary Inspection Questions:				
	Picture 1		Picture 2	
	Yes	No	Yes	No
Is the handpump damaged or loose where it attaches to the cover slab?				
Is the cover slab missing or are there holes or deep cracks in the cover slab?				
Is the inspection port missing a lid or are there holes in the lid?				
If you can see into the well through the inspection port (see the small inset image), are there any cracks or gaps in the wall near the ground surface?				
Is the well missing an apron or are there holes or deep cracks in the apron?				
Is the drainage channel missing or not allowing the spilled water to flow outside of the fence (this could be caused by the channel being blocked, cracked, or not having enough slope for the water to flow down)?				
Is the fence missing or broken so that animals can get close to the well?				
Is there a latrine that is uphill of the well?				
Is there a latrine that is close to the well?				
Are there any other signs of pollution close to the well (e.g. an animal pen, a garbage dump, an area where people do open defecation, a storage area for fuel or pesticides or other chemicals)?				
Are there any uncovered wells close to the well?				

For the last three questions, you might ask what counts as 'close to the well'? The WHO recommends that sources of pollution like latrines or waste dumps should not be within 15 metres of a well or not within 30 metres if they are uphill of the well. But these distances are just estimated guidelines. The actual safe distance for latrines and other sources of pollution depends on the geology and the aquifer in the area where the well has been dug. The two most important factors are the permeability of the ground and the level of the water table. Remember what you learned Section 3: Groundwater. When the water table is close to the surface, pollution can be washed into the aquifer more easily by infiltrating water. When the ground is very permeable, water and pollution can flow quickly through it and sources of pollution must be far away from wells to be safe. In ground that has very low permeability, or when aquifers are confined below an impermeable layer, it can be safe to have sources of pollution closer to wells because the ground does not allow the pollution to flow into the aquifer. Often the permeability of the ground might not be known, so it is safer to keep sources of pollution far away from wells.

Total number of hazards identified for picture 1:		/ 11
Total number of hazards identified for picture 2:		/ 11

Part 2. Taking action to improve water safety.

Based on the results of your sanitary inspection, write a plan for what should be done so that people who drink the water from these wells do not become sick.

Plan for picture 1:

Plan for picture 2:

If you had some money to do these plans, but you could only work on one of them at a time. Which plan would you work on first and why? What additional information would help you decide what to do?

Note: This activity has used the World Health Organisation sanitary inspection guidance for dug wells with handpumps. The WHO also provides guidance for doing sanitary inspections and making water safety management plans for other types of small water supplies including:

- Dug wells that are open, from which water is drawn with a bucket
- Boreholes with handpumps
- Boreholes with motorized pumps
- Small piped water systems
- Spring sources
- Rainwater collection and storage
- Surface water sources
- Household water practices including water collection, treatment and handling, and storage

This guidance can be found on their website: www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/water-safety-and-quality/small-water-supply-management

Comparing methods to speed up sedimentation

Sedimentation is an important step in water treatment, particularly if the water is turbid and full of floating solid particles. Sedimentation occurs as gravity causes these particles to settle at the bottom of a container or pond. Various substances known as coagulants can be added to water to speed up the process of sedimentation, by making the particles group together into clumps. In this experiment, you will compare two different coagulants to see how they affect the rate of sedimentation. Remember to follow any safety instructions from your teacher when doing experiments.

Materials

- 2 litre sample of murky water from a muddy place or a water sample made by mixing dirt and water
- 3 x 2 litre plastic bottles cut in half
- 1 tablespoon of alum (potassium aluminum sulfate)
- Small pestle and mortar
- Moringa seed (1 seed per litre of water, choose good quality seed)
- 2 x tablespoon
- 3 x metal spoon or stirrer
- Funnel
- Timer or clock

Method

1. Grind moringa seed into a powder.
2. Put lid on original sample and shake.
3. Use a funnel to pour the same amount of water into each bottle.
4. Add ground moringa seed to one bottle and a tablespoon of alum powder to another; Stir all three bottles for 5 minutes. Stop stirring and start the timer.
5. Record your observations of the appearance of each bottle at the start, and then at 5 minute intervals.

Student observations

Water appearance	No treatment	Alum	Moringa seed
Appearance and smell before the start of treatment			
Appearance 5 minutes after adding coagulant			
10 minutes after adding coagulant			
15 minutes after adding coagulant			
20 minutes after adding coagulant			
30 minutes after adding coagulant			
Which treatment worked fastest?			

Extension: Investigate how turbidity is measured

Materials

- A flashlight
- Four flat-bottomed transparent cylindrical drinking glasses
- Samples of 1) unfiltered water (the original untreated water), 2) water after sedimentation with alum, 3) water after sedimentation with moringa, and 4) the clearest water you can find

Method

1. Pour equal volumes of each type of water into the flat-bottomed transparent drinking glasses.
2. Move the glasses of water into a dark room and place them on a flat surface.
3. Place the flashlight against the side of each container and shine a beam of light through each of the samples. Look at the path of the flashlight beam.
4. How does the path of the flashlight beam through filtered water compare to that through unfiltered water? How does the filtered water compare to the clearest water?
5. Now pour half of the unfiltered water out and replace it with clear the clearest water. Examine the effect by shining the flashlight through the glass. How many times must you repeat this dilution before you can see no difference between the what started as unfiltered water and the clearest water?

Why does the path of the flashlight tell us anything about the turbidity? The reason is that the particles in the water scatter the light from the flashlight. Scientists studying water quality often use turbidity meters called nephelometers which measure how much light is scattered at different angles. As more particles cause more scattering of the light, the nephelometer is designed to provide a precise measurement of turbidity, which is given in Nephelometric Turbidity Units (NTU). (Nephele was the ancient Greek goddess of clouds.)

This activity has been adapted from the Global Experiment that was conducted during the International Year of Chemistry, 2011.

Solar still design challenge

The solar still is a device that that uses solar energy to purify water. Different versions of solar stills are used to desalinate seawater and in desert survival kits. Solar stills are also available for home water purification.

In this activity you will build a solar still and find out how it can purify water. You will be challenged to use your knowledge to build a more efficient solar still. Follow your teacher's instructions to complete this activity.

Water quality crossword

Test your water protection and treatment knowledge by using the clues to fill in this crossword puzzle.

ACROSS – Clues for horizontal words:

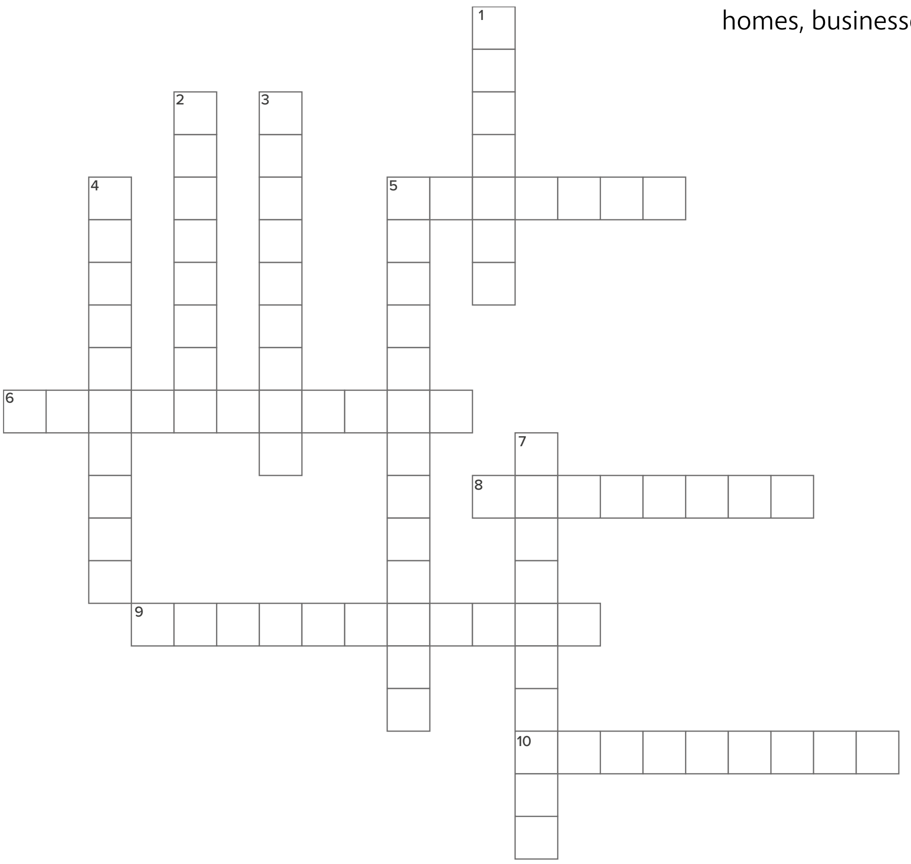
5 Something that can dissolve other substances (7 letters)

6 A person that is impacted by / has an interest in the decisions made for a water source (11 letters)

8 A biological organism (often bacteria or viruses) that causes disease (8 letters)

9 Radiation that comes from the sun and has a wavelength shorter than visible light (11 letters)

10 A measure of the cloudiness/haziness of water due to suspended particles (9 letters)



DOWN – Clues for vertical words:

1 A ring-shaped hole that forms between the sides of a drilled hole and the pipe or casing that is installed in the hole (7 letters)

2 A flexible sheet-like material that acts as a boundary so that some substances are blocked from moving through it (8 letters)

3 The process by which the physical, chemical or biological properties of water are changed by addition of any substance that makes the water harmful to humans or the environment (9 letters)

4 The action of passing water through a device / material to remove unwanted substances (10 letters)

5 The treatment step used to clarify turbid water before using a filter (13 letters)

7 Water that contains unwanted materials from homes, businesses and industries (10 letters)

5. Water management

In *Section 1: The Water Cycle*, *Section 2: Geology*, and *Section 3: Groundwater*, you learned about how water changes form and moves between the atmosphere, the surface, and the ground. From what you have learned and from your own experiences, you will know that humans impact the water cycle in many ways. Human activity often influences the quality of surface and groundwater, as you learned in *Section 4: Water Quality*. And people can also change how water is stored and where it moves by building structures that affect water flow, for example, dams that form reservoirs, boreholes for pumping water out of aquifers, or canals to irrigate fields for growing crops. When water is taken from the natural cycle for **consumptive use** in agriculture, industry, and domestic activities, the amount of water stored in lakes, reservoirs or the ground can be reduced.

Have a look at the water cycle image on page 52. It includes examples of some human activity. In what ways do human activities cause changes in the water cycle where you live?

How much water do you use?

You may or may not use water to grow your own food or make things yourself, but if you think about what you eat, what you wear, and even the buildings and roads that you use – water will have been involved in the production, transport, and construction of all these products and infrastructure.

When you step on sand, you can make a mark that is the size of your foot, which is called a footprint. When you use water, for drinking and washing and through the food, products, and infrastructure that you consume or use, you make an impact on the water cycle – this can be called your "water footprint". The more water that you use (both directly and indirectly through food and other items) the bigger your water footprint is. A water footprint can be divided into different categories including abstracted water, rainwater used by plants, and wastewater that contains pollutants. The Water Footprint Network calls these "blue, green and grey" water footprints (waterfootrprint.org).

ABSTRACTION footprint

The water taken and used from rivers, lakes or aquifers e.g. for farming or use in a factory

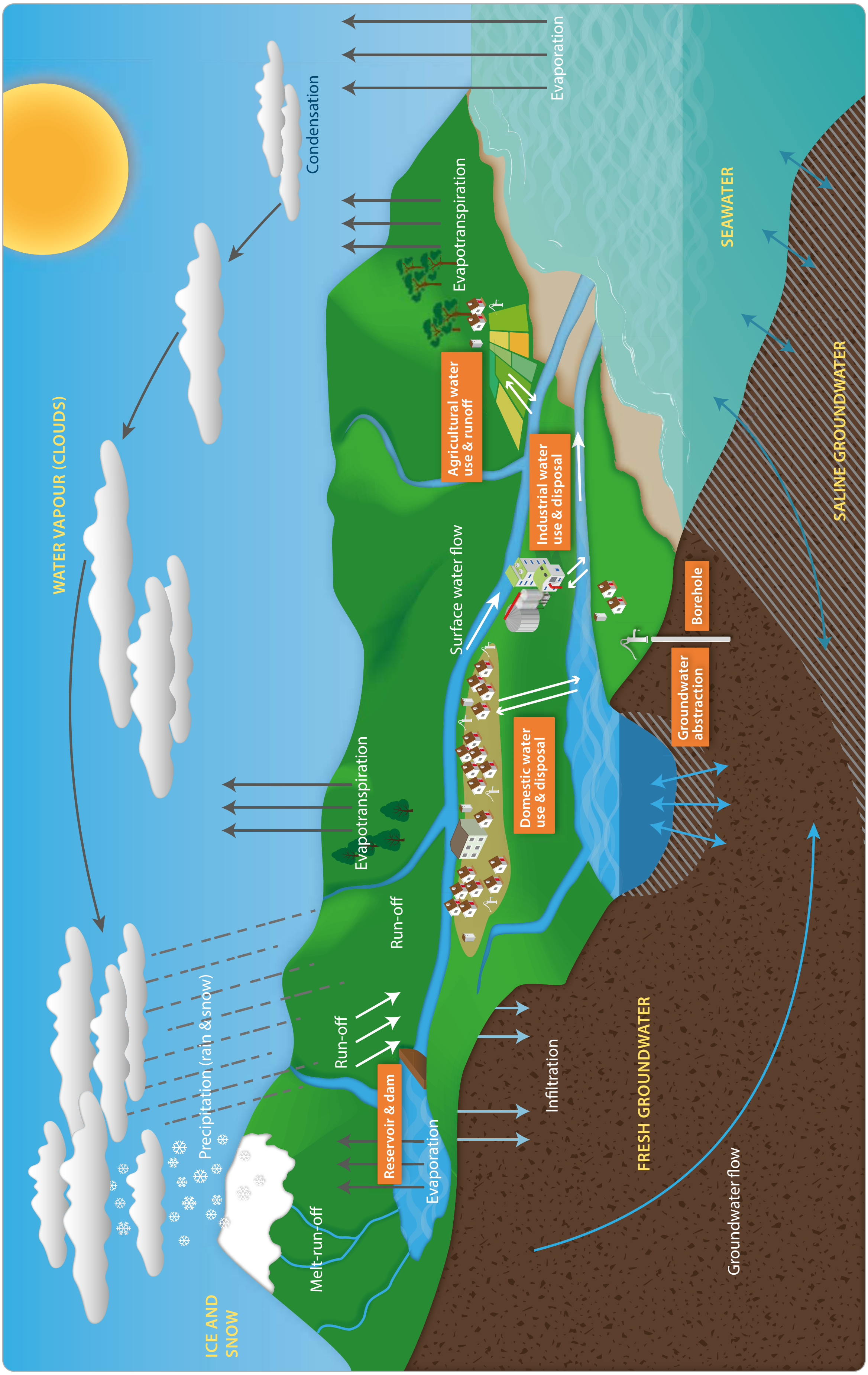
RAINWATER footprint

The rainwater used by plants that are then consumed by people or livestock

WASTEWATER footprint

The freshwater that is needed to dilute pollutants from households, farms or factories enough to meet specific water quality standards

waterfootprint.org



■ The water cycle including some human activity

All of the items that you use have their own water footprints. The water footprint of an item is the total amount of water required to produce it. For example, a bag of rice that you can buy in a shop has a water footprint – this includes the amount of water that was used to grow the rice, the water that would be needed to dilute any pollution from pesticides or fertilizers that were applied to the rice to make it grow better, the water used to produce the bag that the rice is in, and the water used to transport it to the shop. To calculate your own personal water footprint, you would have to add up the footprints of all the items you consume and use.

Food that requires a lot of water to grow (like rice for example) or items that require a lot of water to produce (like a car for example) are called "**water intensive**". In the same way, industries that use a lot of water are also called water intensive. Globally, the agricultural industry that produces food is the most water intensive industry. Meat and animal products have particularly large water footprints because water is needed for the animals to drink and also to grow food for them, and because livestock can produce a lot of polluting waste. The textile industry that produces clothing is also very water intensive.

What is water management?

You have learned that water is important for many different purposes - it is needed for drinking and to grow food and produce all of the items that we use. In *Section 1: The Water Cycle*, you learned that water is not evenly distributed around the world – some places have a lot of water, and some places have very little water. And you learned that the amount of water that is available in any area can change over time due to weather variability and long-term climate change. All of this means that people need to make good decisions about how to use water and what to use it for.

Water **management** is the process of controlling how water is moved and used to minimise damages (like water scarcity, flooding, and pollution) and maximise benefits (like supplying clean drinking water, growing food, and producing things for people to use). There is always a limited amount of water, so people must decide how much water to abstract from the water cycle, what it can be used for, and how it is returned to the water cycle – including how polluted wastewater should be treated and discharged.

Rice paddies in Vietnam. A lot of water is needed to grow rice. Photo by chericbaker. CC BY-NC-ND.

What other water intensive industries can you think of? What do you think is the most water intensive industry in your country?

What do you think are the most water intensive crops grown in your country?

Look at the wastewater footprint definition. Thinking back to the chapter about water quality, why is dilution one way to reduce the impact of pollution?

If you were responsible for creating a budget for managing the drinking water supply in your area, what proportion of the money would you give to expanding the supply, and what proportion would you keep for maintaining the equipment?

What proportion would you spend on treating the water? Can you think of any other costs that should be considered for managing drinking water supplies?

Mechanics fixing a water point. Photo by Nancy Gladstone.

Water management also involves decisions about how to spend funding. For drinking-water supplies for example, someone must decide how much money should be spent on:

a. installation of new pipes and boreholes so that more people can be supplied,

b. **maintenance** activity to keep water systems functioning well over time, or

c. water treatment chemicals (like alum for sedimentation or chlorine for disinfection) and treatment facilities to improve the quality of the water.

Who makes decisions about how water is managed?

In the government, people make **policies** and laws about water. Policies and laws are used to guide or control the decisions that people and organisations make so that water is managed in the way that the government wants it to be. Regulators (people who work for regulatory agencies, which are a special part of the government) are responsible for making sure that policies and laws are being followed.

Often national policies and laws about water are influenced by goals and guidance created by international organisations. For example, governments often refer to the United Nations' Sustainable Development Goals and the guidance on drinking water quality standards from the World Health Organisation. In democracies, government policies and laws are usually also influenced by what the government thinks is important to their supporters / voters.

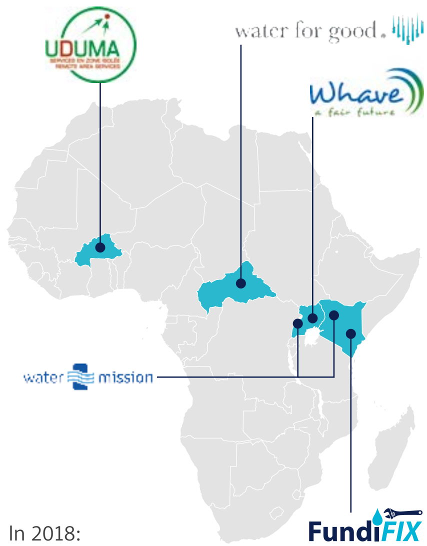
If you worked in the Ministry of Water, what policy would you want to make?

Many scientists, engineers, and management professionals also influence decisions about water. Some do research and use the data that they gather to advise the government on what policies and laws are needed. Others work on designing, building, and operating water supplies – they operate water treatment plants for example, or design and build dams, or are responsible for collecting data and writing reports to a regulatory agency to show whether laws and policies are being followed.

> Planning for the future is an important part of water management. If you were a scientist trying to figure out how much water a city will need 20 years in the future, how would you do it?

Businesses and people who work in industry also make decisions about water, including how much water they use and how much pollution they release into surface waterbodies and groundwater aquifers. Sometimes these decisions are guided by government policies and laws. Using too much water or causing a lot of pollution can have consequences like having to pay fines or facing criminal charges and possibly going to jail in very serious cases. But when strong policies or laws have not been made or are not enforced, businesses and companies decide for themselves how they will use water and what kind of impact their activities will have. In these situations, if companies are careless about how they use water, it may have a damaging impact on people and the environment.

People also make water management decisions in communities, especially in rural areas. In rural areas, large piped water supplies are not common. Instead, small water supplies are often built by the government, NGOs, or communities themselves. After a water supply is constructed, communities often select people to form a water management committee that is responsible for managing the water supply. One of the biggest challenges that these committees face is keeping the water supplies in good condition and fixing breakdowns. In some places, service providers are helping with this challenge by offering maintenance services for rural water supplies. The image on the right highlights five service providers that are working in Kenya, Uganda, the Central African Republic, and Burkina Faso with data on their activities in 2018.



In 2018:
5 service providers

Working in:
14 operational areas

Maintained over:
2800 waterpoints

800+ piped waterpoints from **99** schemes

1950 handpumps

Serving an estimated:
1 million people

Managing water for sustainable agriculture

One of the most important uses of water is for growing crops. From small gardens to huge industrially-managed farms and plantations, all agriculture needs water. Where large amounts of water are used, we need to think about sustainability – will the water be used up too quickly for it to be replaced by rainfall? Will pesticides or fertilizers pollute run-off water from farms and cause problems for the environment and human health? What can farmers and gardeners do to use water more efficiently and to limit pollution?

> What decisions about water use are made by people in their households? Are these decisions different in rural areas compared to cities?

> Can you find out who makes decisions about water at your school? What are the biggest challenges that they must manage?

Taita, Kenya, Terraced Farmland, Upland. Photo by Peter R Steward, CC by NC 2.0, Flickr.com.

Drip irrigation at a primary school in Kwale County, Kenya. Photo by Saskia Nowicki.

Watering crops in a greywater tower, Ethiopia. Photo by Sustainable sanitation, CC BY 2.0 Flickr.com.

Ways that farmers protect soil and conserve water

However large or small a farm is, the harvest depends on soil and water so farmers who are concerned with long term sustainability develop ways to protect both of these resources. Different conservation techniques may be needed depending on the type of soil and seasonal patterns of rainfall, and farmers may need to adapt as the climate changes. Some examples from conservation agriculture include:

- Building terraces to prevent soil being washed away and allow the harvest rainwater and run-off for re-use on the farm
- Building cut-off drains and ditches to retain water in the soil
- Planting drought-resistant indigenous plants adapted to the local climate and/or varieties of crops that need less water
- Composting and mulching – Organic matter can be used as a surface mulch layer or rotted down to compost and mixed into the soil. These practices improve soil structure which results in better drainage: Water does not pool on the surface and evaporate or sit in the soil and cause rotten roots, but rather seeps gradually into and through the soil at a rate which allows plants to make good use of it
- Some farmers now use targeted “drip” irrigation systems that transport water to crops through pipes and release water as needed. The purpose of these systems is to avoid wasting water to evaporation. Systems are available for small farms and even some schools use them. It is important to monitor how effective they are.

Using greywater on plants

Another possibility for conserving water is to use greywater – the wastewater from household activities like cooking and washing – on crops or other plants. In this way, greywater can become **recycled water**. Professionally-designed greywater systems can be installed to filter, treat, and store the water to make it safer and easier to re-use, but it is important to get expert advice on the costs and benefits of installing such a system.

Most simply, greywater can be collected in a bucket or other large container and transferred to the garden directly, but it is important to pay attention to the safety guidelines in the learning actvities below.

What happens to greywater at your school?

The water cycle where I live

You could do this activity individually or in groups of 2–4. If you are working in groups, pause at each ✱ to get feedback from each group; if individually, turn to your neighbour and discuss. You can use what other people came up with to add to your lists and tables.

1. Make a list of ways people use water in your area during the rainy season.
2. Look at the diagram of the water cycle including human activity. Are the items on your first list included in the diagram? ✱
3. Make a list of places where people in your area get water from.
4. Look at the diagram of the water cycle including human activity. Are the items on your second list included in the diagram? ✱
5. Here are the labels from the water cycle diagram including human activity. Circle the labels which show the ways in which water moves around the cycle. (Clue: You should circle 13 of them).

Condensation
Precipitation
Borehole
Surface water flow
Groundwater abstraction
Evaporation
Saline groundwater
Groundwater flow
Infiltration
Run-off
Dam
Industrial water use and disposal
Reservoir
Evapotranspiration
Agricultural water use and run-off
Melt-run-off
Domestic water use and disposal

6. Building on the table that was created in the activity on page 8, fill in the rows and columns for each of the circled words. Which of the processes have you seen, and which are taking place where you live?
7. You can do this final step with everyone together, or continue to work in small groups. Put each of the words from your two lists, plus each of the circled words showing processes on to pieces of paper. Arrange them into a water cycle. Use a pen or more paper to make arrows to show the flow of water around your diagram.
8. Discuss as a group: How would your diagram change during the dry season when there is less rain? Does your diagram explain everything about where the water used in your area comes from and goes to? What else does your diagram make you want to find out?

Conservation agriculture project

Which food crop plants growing in your area use the most water and which ones use the least?

Is there a gardener or farmer that you could ask about this or can you think of a way to measure it directly?

Can you find out about some of the water-saving techniques that are used by farmers in your area?

Are there any water-saving techniques that could be used in the gardens at your school?

Greywater Safety Guidelines

- Water from toilets or washing soiled nappies (**blackwater**) is not safe for re-use due to faecal contamination
- Residential gardens close to streams or shallow water tables should not be irrigated with laundry water: There is a risk of ground and surface water contamination from salts and other non-biodegradable substances found in washing powder or other laundry products; Long-term use at one site may pose a risk to soil quality
- Shower and bath water or water from a bathroom hand basin is most appropriate for use in the garden because the residues from soap/cleaning products are small
- Kitchen sink water can be used if it does not contain oil/grease or blood
- Filter the water before use so that any lint, hair and food particles are removed to reduce bad odours and avoid attracting pests. A filter could be a sock over the end of the pipe/hose, a simple sand/gravel filter, or something professionally-designed. The filter will need to be cleaned regularly.

Important safety points for using greywater

- To avoid bacteria growth, do not store greywater for more than 24 hours before using it.
- Greywater should be used on crops in combination with freshwater to avoid build-up of salts that are bad for plants. To address this issue, pour freshwater on the crops/soil at least once a month if it has not been raining.
- Don't use greywater on vegetables where you eat the leaves or on crops that will be eaten uncooked.
- Don't pour greywater directly onto leaves or spray it into the air, pour it directly onto the ground – this reduces the health risk from bacteria
- Ideally, pour the greywater onto a mulch (a surface layer of organic matter used in gardening; learn more in the next section!) rather than bare soil so that it filters slowly into the soil below; Alternatively, find out more about the construction of greywater towers which filter water before supplying it to crops
- **Wash crops with clean water and / or cook them before eating**

Can a t-shirt have a footprint?

T-shirts are often made of cotton, which is a crop grown in many countries around the world. You can read about cotton production in India in the newspaper article on the following page. “Blue” and “Green” water (see diagram on page 51) is used for irrigation and also in the process of preparing and dying the final cotton textile used to make the t-shirt. The WASTEwater footprint of a t-shirt depends on how much pollution was caused by its production from the pesticides, dyes and any other chemicals used in the process. All these elements can be put together to estimate the total water footprint of a t-shirt.

If you can find a t-shirt with a label showing where the cotton was grown, you can use the information below to calculate the water footprint of that t-shirt. You will also need a weighing machine or use the average t-shirt weight of 0.25kg.

Where was it made? (Check the label)

Country	Water footprint to produce 1 kilogram (kg) of cotton
USA	8,100 litres (L) of water
China	6000 L
Pakistan	9,600 L
Uzbekistan	9200 L
India	22,500 L
Global Average	10,000 L

Weight of one t-shirt:

Remember 1 kilogram = 1,000 grams	(kg)

Calculate the water footprint of the t-shirt

Water footprint of cotton (in L per kg)	T-shirt weight (in kg)	Water footprint of t-shirt (in L)
x	=	

Figures from The Water Footprint of Modern Consumer Society by Arjen Y. Hoekstra, Routledge, 2013

Why do the water footprints for cotton produced in different countries vary so much?

If you can watch videos in school, ask your teacher about a video called Cotton and Water to find out about ways to reduce water use in cotton production.

Cotton harvest. Photo by Kimberly Varden; CC BY 2.0; Flickr.com.

Extract from Guardian newspaper article from World Water Day 2015

The cost of cotton in water-challenged India

Stephen Leahy
Friday 20 March 2015 14.12 GMT

Severe water scarcity in India is exacerbated by the cotton industry. Concerns are high, but are businesses,consumers and government doing enough?

You might not realise it, but India exports enormous amounts of water when it exports raw materials such as cotton and products such as automobiles.

The water consumed to grow India's cotton exports in 2013 would be enough to supply 85% of the country's 1.24 billion people with 100 litres of water every day for a year. Meanwhile, more than 100 million people in India do not have access to safe water.

Virtual water

Cotton is by no means India's largest export commodity – petroleum products followed by gems and jewellery follow closely behind. All of these exports require water to produce, and the quantities needed are staggering. Not only does it take water to grow anything, it also takes water to make anything: cars, furniture, books, electronics, buildings, jewellery, toys and even electricity. This water that goes largely unseen is called virtual water.

What's easy to forget is that virtual water is as real as the water you drink. Producing 1kg of cotton in India consumes 22,500 litres of water, on average, according to research done by the Water Footprint Network. In other words, this 22,500 litres of water cannot be used for anything else because it has either evaporated or is too contaminated for reuse.

By exporting more than 7.5m bales of cotton in 2013, India also exported about 38bn cubic metres of virtual water. Those 38bn cubic metres consumed in production of all that cotton weren't used for anything else. Yet, this amount of water would more than meet the daily needs of 85% of India's vast population for a year.

Doing things differently

Cotton doesn't usually consume this much water. The global average water footprint for 1kg of cotton is 10,000 litres. Even with irrigation, US cotton uses just 8,000 litres per kg. The far higher water footprint for India's cotton is due to inefficient water use and high rates of water pollution — about 50% of all pesticides used in the country are in cotton production.

Most of India's cotton is grown in drier regions and the government subsidises the costs of farmers' electric pumps, placing no limits on the volumes of groundwater extracted at little or no cost. This has created a widespread pattern of unsustainable water use and strained electrical grids.

Recent reports show that India's water consumption is far too high. In 54% of the country 40 to 80% of annually available surface water is used. To be sustainable, consumption should be no more than 20% in humid zones and 5% in dry areas, to maintain the ecological function of rivers and wetlands, experts say.

India's extensive groundwater resources are also rapidly being depleted, with 58% of wells in the drier north-west India experiencing declining water levels.

Water management crossword

Test your knowledge by using the clues to fill in this crossword puzzle.

ACROSS: Clues for horizontal words

2. A procedure, protocol, or set of principles, often created by people in the government, that is used to guide decisions (6 letters)

4. The total amount of water directly and indirectly used by a person, or the total amount of water used to produce something (2 words, 5, 9 letters)

7. Use of a resource that lowers the amount that is available for use over time, such as removing water from a lake or aquifer and not returning the same amount back (2 words, 11, 3 letters)

8. The activity of deciding and controlling how a resource like water is used (10 letters)

9. Prevention of wasteful use of a resource such as water (12 letters)

10. A small group of people selected by a larger group to represent them and do a set of tasks (9 letters)

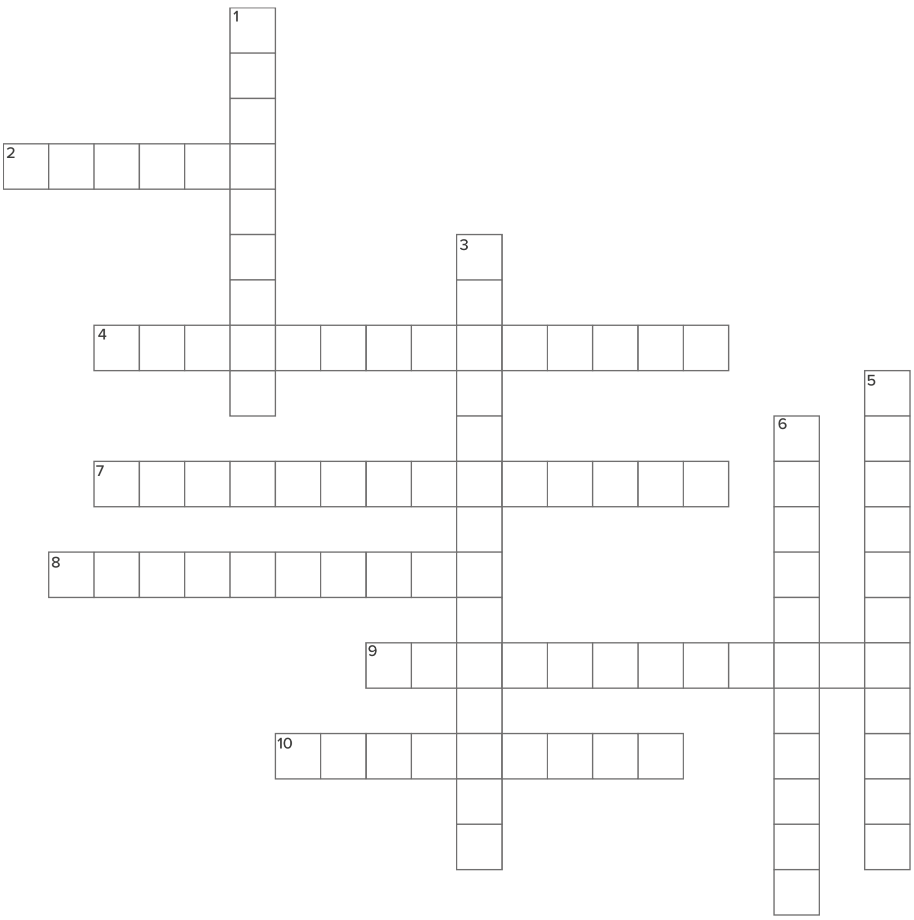
DOWN: Clues for vertical words

1. The wastewater from household activities like cooking and washing (9 letters)

3. A description of an industry that uses a lot of water (2 words, 5, 9 letters)

5. Activity that is done to keep something working or in good condition (11 letters)

6. Continuing at the same speed or amount without breakdown or depletion (11 letters)



Use your water knowledge

Choose two questions from the list below and discuss in pairs or small groups to get your ideas flowing.

Make a poster, write a school newsletter article, or create an awareness campaign on the theme of OUR VISION FOR WATER to share what you have learned in this module with others.

Discussion points

- Who is responsible for making water safe to drink?
- Who is responsible for making sure there is enough water for everyone?
- How much water is enough water for drinking and household activities?
- How much water do people in your school use every day? Do you think the water footprint of your school should be reduced or increased? If so, how would you do that?
- How can commercial users of water like agriculture, factories or mines conserve water and protect supplies?
- What are the main risks of drinking unsafe water and what can be done to reduce the risks?
- Why is groundwater from a handpump usually safer to drink than water collected from a lake, river or open well? What can be done to protect the safety of groundwater?
- What do you think everyone should know about water?
- What are the best ways to share important messages about water?

Hold a debate

Organise a debate with a water management theme. Some examples might be:

We believe that greywater should be used in agriculture and gardening because it is a form of water recycling that helps to conserve water.

VS.

We believe that greywater should not be used in agriculture and gardening because it contains soap, other chemicals, and possibly pathogens from household activities that could be harmful.

Or,

We believe that paleowater in old aquifers should be abstracted and used because it can provide supply for drinking, growing food, and economic production. It is not useful for anything if it stays in the ground.

VS.

We believe that paleowater in old aquifers should not be abstracted because it is a non-renewable supply and when it is depleted it will be difficult for people to find another water supply and there will be water scarcity.

Glossary

Term	Definition
abstraction	the process of removing something, such as taking water out of the ground or out of a surface water body
Afridev	a handpump design that was created based on research in Africa and is commonly used throughout the continent
aquiclude	a layer of geological material that is **impermeable**; it blocks water and does not allow it to flow through
aquifer	an underground geological formation that stores and yields water
aquifer pathway	a route that solutes (substances dissolved in water) and microorganisms (bacteria, protozoa, viruses) can travel where they move down through the ground into an aquifer and then flow with the groundwater into an abstraction point like a well or borehole
aquitard	a layer of geological material that has low **permeability**; it slows down the flow of water
biogenic	created by living organisms
blackwater	wastewater that contains faeces
borehole	a deep, narrow hole made in the ground, often to locate/pump out water or oil
climate	the general pattern and conditions of weather in an area over a long period of time – descriptions of climate are often based on averages of weather variables like rainfall and temperature over many years
climatology	the scientific study of the climate
committee	a small group of people chosen to represent a larger group of people and do a set of tasks; in rural areas, communities often select people to form a water management committee that is responsible for managing a water supply that the community uses
compost	organic material from plants and animals that has decayed (become rotten or broken down by bacteria or fungi) and can be used to provide nutrients for growing plants
concentration	the relative amount of a substance contained in a particular volume of a solution, mixture, or space
condensation	the process by which a vapour becomes a liquid often due to cooling
conservation	prevention of wasteful use of a resource such as water
consumptive use	use of a resource that reduces the supply: such as removing water from a river, lake or aquifer without returning the same amount (e.g. consumption of water by plants, humans, and animals and the incorporation of water into the products of industry or food)
discharge	water flowing out (e.g. out of a stream, pipe, or aquifer); the opposite of recharge
disinfection	cleaning something by killing the microorganisms (bacteria, protozoans, viruses) that are in it (e.g. water) or on it (e.g. a table)
drought	an extended period of less than normal precipitation that often affects availability of water supplies, it is a natural hazard caused by climate variability

Term	Definition
evaporation	conversion of a liquid (water) into a vapour (a gas) usually through application of heat energy
evapotranspiration	movement of water vapour into the atmosphere due to both evaporation from soil and transpiration from plants
filtration	the process of passing water through a device/material to remove unwanted substances
fracture	a break or crack in a hard object or material like rock or bone
geology	the scientific study of the physical structure and substance of the Earth
glacier	a slow-moving mass or river of ice formed by the accumulation of snow over many years on mountains or in the Arctic or Antarctic regions
greywater	wastewater from household activities like cooking and washing
hydrogeology	the scientific study of groundwater and the geological and non-geological materials that it interacts with
hydrology	the scientific study of the characteristics and movement of water
impermeable	what we call material that water cannot flow through; it does not have connected void spaces so it blocks the flow of water
improved water source	improved drinking water sources are those that have the potential to deliver safe water by nature of their design and construction, and include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water
infiltration	movement of water from the land surface into the subsurface/ground
installation	building or putting something in place (e.g. a water system)
intensive	involving the use of a lot a resource such as water, land, or time; something is water intensive when it uses a lot of water.
interflow	water travelling horizontally through shallow ground during or soon after precipitation (it discharges quickly into a stream or other waterbody but does not move down below the water table)
irrigation	controlled application of water to agricultural fields to supplement the water that is supplied by precipitation
localised pathway	a route that solutes (substances dissolved in water) and microorganisms (bacteria, protozoa, viruses) can travel to get into a well or borehole by moving through the ground very nearby or falling directly into the well/borehole
maintenance	the activity of keeping something working or preserving a condition or situation; for example, mechanics do maintenance work on machines and equipment like cars or handpumps to keep them working
management	the activity of being responsible for the running of an organisation or the activity of deciding and controlling how a resource is used; water management is the process of controlling how water is used
membrane	a flexible sheet-like material that acts as a boundary, lining, or partition so that some substances are blocked from moving through it
microbiology	the scientific study of microorganisms, which are very small creatures including viruses, bacteria, protozoans and some worms
molten	liquefied by heat (usually refers to melted rock, metal, or glass)

Term	Definition
non-renewable	non-renewable resources are finite – e.g. a goldmine – once the gold deposits are mined out, no more gold will be formed in that place.
organic	relating to or created by living organisms (plants, animals, bacteria, fungi, protists).
over-abstraction	withdrawal (removal) of groundwater over a period that exceeds the amount of water recharged to the aquifer
paleowater	groundwater that has been stored in an aquifer for thousands to millions of years; typically, it is recharged once after several thousand years or longer, or not at all
pathogen	a biological organism (often bacteria or viruses) that causes disease
permeability	a measure of the connectivity of void spaces in the ground
permeable	what we call material that has connected void spaces so water can flow through it
policy	a system of principles to guide decisions to achieve intended results; a policy is often in the form of procedures or protocols for action; it is created by people or organisations, often part of the government, to guide the activity of other people or organisations
pollutant	any substance that when added to water (or another substance) makes it impure and unfit for consumption or an intended use
pollution	changing the physical, chemical, or biological properties of water by introducing any substance that makes the water harmful to use
population density	the number of people per unit of area e.g., number of people per square kilometre – a figure used to compare how many people are living in different towns, countries or regions
pore spaces	void spaces between geological material
porosity	the ratio of the volume of void or air spaces in a rock or sediment to the total volume of the rock or sediment
potentiometric surface	an imaginary level above a confined aquifer – the level to which water from a confined aquifer would rise to in a pipe because it is under pressure exceeding that of atmospheric pressure
precipitation	water falling out of the atmosphere in a liquid or solid state
recharge	water that is added to an aquifer (e.g. when rain infiltrates into the ground)
recycled water	water that is used more than one time before it returns back into the natural water cycle
reservoir	a body of water that forms behind a dam
run-off	water that flows over land to surface streams, rivers, and lakes and eventually to the ocean/sea
rural	adjective referring to countryside areas rather than town or city areas, which are described as 'urban'
sanitary	the condition of a clean environment that is free from pollution, especially free from faecal waste that can spread microbiological pathogens
saturated	what we call material (like soil or a sponge) that is holding as much water as possible
saturated zone	the area below the water table where the ground is saturated with water (all the void spaces are filled with water)
sedimentation	the process of suspended material settling or 'falling' out of water, being deposited as a sediment
seepage	when water moves into the ground from a surface waterbody (e.g. some water from lakes and rivers moves down into the ground) or out of the ground into the ocean or onto land

Term	Definition
soil	the top layer of the Earth's surface, containing unconsolidated rock and mineral particles mixed with organic material
soil moisture	water clinging to soil in the unsaturated zone
solvent	something that can dissolve other substances
stakeholder	a person who is impacted by and / or has an interest in a project, business, or other activities of an organisation (e.g., all the people who are impacted by or have a responsibility for the management of a water source are stakeholders for that water source – this would usually include community members, government officials, and possibly owners or company employees)
surface water	water in rivers, lakes and streams on the land surface
sustainable	able to continue at the same speed or amount, with the same inputs and outputs, without having a breakdown or depleting (lowering the amount of) a resource
transpiration	the process by which water absorbed by plants, usually through their roots, is released into the atmosphere, mostly through the leaves of the plant, due to photosynthesis (photosynthesis is the process that plants use to transform sunlight into energy that they can use - the process produces oxygen and water in gaseous form)
turbidity	a measure of the cloudiness/haziness of water due to suspended particles (often silt or organic matter)
ultraviolet light	radiation that comes from the sun and has a wavelength shorter than visible light
unsaturated zone	the zone between the land surface and the water table where pore space contains both water and air (plant roots can capture the moisture passing through this zone, but it is not enough water to fill wells)
vapour	the state of water in which individual molecules are highly energized and move about freely; also known as gas/gaseous
wastewater	water that contains unwanted materials from homes, businesses, and industries; a mixture of water and dissolved or suspended substances
water intensive	phrase used to describe a process or activity that requires a lot of water
water quality	the chemical, physical, and biological characteristics of water with respect to its suitability for a particular use
water scarcity	when there is not enough water to satisfy the needs of people, animals and the environment in a region (when water demand is greater than water supply)
water table	the level in the ground below which the soil and rock are fully saturated with water (all the spaces are filled with water); this is the name for the top of an unconfined aquifer
water treatment	steps that can be taken to remove harmful chemicals and pathogens from water, such as sedimentation, filtration and disinfection
waterbody	any significant accumulation of liquid water such as a lake, sea or river
weathering	the process of materials like rock, wood, or metal breaking down over time because of contact with air, water, changing temperatures, and biological organisms (animals, plants, bacteria, and fungi)

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About this publication

The first edition of the Water Module was created and tested in Kenya by Saskia Nowicki, Nancy Gladstone, Jacob Katuva, Heloise Greeff and Dr Achut Manandhar (University of Oxford), Geofrey Wekesa and Geofrey Mwania (Base Titanium Environmental Education Programme) with input from teachers and students at Kingwede Girls Secondary School, Shimba Hills Secondary School and Mivumoni Secondary School in Kwale County, Kenya and assistance from Calvince Wara, Fauzia Mumbua Swaleh and Willy Sasaka (Rural Focus Ltd.). It was reviewed and improved upon by Dr Georgina Jones (Base Titanium), Prof. Dan Olago (University of Nairobi), Prof. Bancy Mati and Prof. John Gathenya (Jomo Kenyatta University of Agriculture and Technology), Mike Thomas and Mike Lane (Rural Focus Ltd.), Dr Albert Folch and Nuria Ferrer Ramos (Universitat Politècnica de Catalunya), Dr Rob Hope, Patrick Thomson and Dr Caitlin McElroy (University of Oxford).

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The staff and pupils from Kingwede Girls, Shimba Hills and Mivumoni Secondary Schools, Kwale County, Kenya who helped develop the Water Module.

Photos taken at Water Club activity days.

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