MINISTRY OF HEALTH
MANATŪ HAUORA

Pathogens and Pathways, and Small Drinking-water Supplies

Resources for the Drinking-water Assistance Programme

2007

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1 Introduction

This booklet and accompanying DVD with the same title provides information about the supply of safe drinking-water to small water supplies serving fewer than 5000 people. For more information contact your regional Technical Assistance Programme (TAP) Facilitator at your local Public Health Unit.

Communities need to make sure their water is safe to drink and that there are no micro-organisms or other unwelcome contaminants present that could make you sick. Micro-organisms are of particular concern as they can multiply very quickly – so it doesn't take many micro-organisms to cause illness. Contamination of a water supply is especially significant to a community as the water is reticulated to everyone's home via a network of pipes. So it only takes one thing to go wrong for a lot of people to be affected.

2 What is a Micro-organism?

The most common micro-organisms found in water fall into five categories: bacteria, protozoa, viruses, helminths (or worms) and cyanobacteria. A few examples from each of these categories are given in Table 1 below.

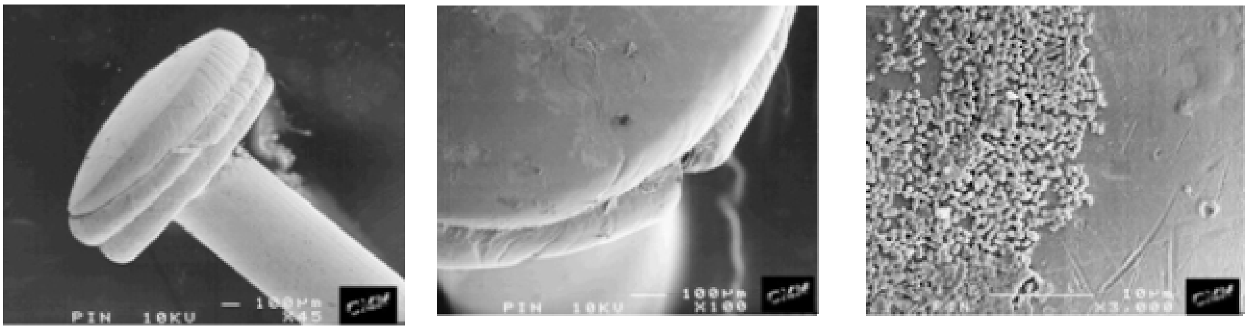
Table 1: Examples from some common categories of micro-organisms

Category	Examples
Viruses	Hepatitis A, flu virus, polio
Bacteria	Campylobacter, Salmonella, Shigella
Protozoa	*Cryptosporidium*, *Giardia*
Helminths	Thread worms, tape worms, nematodes
Cyanobacteria	Cylindrospermopsin

Some of these micro-organisms may be found naturally in the water supply. Most micro-organisms are not a problem for humans. For example, bacteria are used to make yoghurt, and bread is made with yeast (which is a type of fungus).

Size is very important when discussing micro-organisms. To put their size in context, when we talk about cows, sheep and humans, for example, we measure their size in metres (m); if we divide 1 metre by 1000 we get 1 millimetre (mm), and we can use millimetres to measure of the size of ants and most other insects. Then, if we divide 1 millimetre by 1000, we get 1 micrometre or 1 micron (µm) – and we use micrometres to measure the size of bacteria and other micro-organisms. The images of bacteria on a pinhead in Figure 1 below give some idea of how small that is. But we don't stop there, because if we divide 1 micron by 1000 we get 1 nanometre (nm) – this is the measurement of wavelengths of light and the size of viruses. So the polio virus, for example, is 600,000 times smaller than a human yet it can still make us sick.

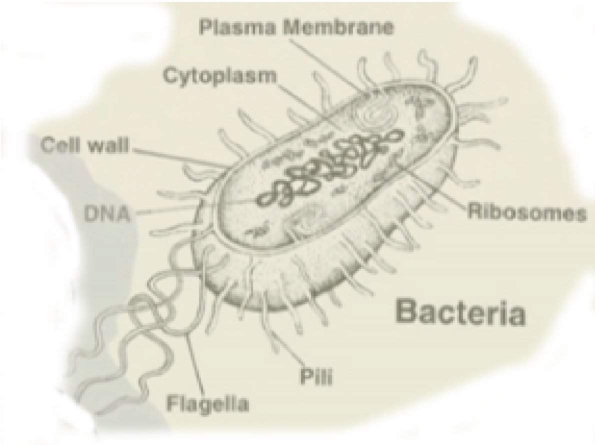
Figure 1: Bacteria on the head of a pin



x 45 magnification x 100 magnification x 3000 magnification

Source: University of Queensland, URL: www.uq.edu.au

2.1 Bacteria

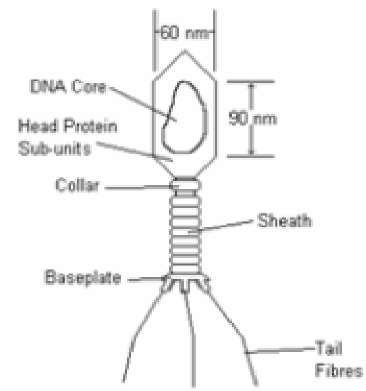


On average, bacteria are 0.5 to 1 micron in diameter and 4 to 20 microns in length. (A micron is one-millionth of a metre.) Bacteria are found everywhere, covering all surfaces, and therefore can be found naturally in both **groundwater** and **surface water**. Most bacteria have little impact on our day-to-day lives but some kinds are harmful to us.

Bacteria breed by dividing in two with no need for another bacterium to be present. This process is called **asexual reproduction** – there are no males and females. It means that, when they mature, the bacterial cells split in two. Through this process, the number of bacteria can increase quickly in a very short period. Some can double their numbers every 20–30 minutes. In other words, one bacteria cell can become as many as 1 trillion cells – 1,000,000,000,000 bacteria – within 24 hours!

Community water supplies are monitored for levels of indicator bacteria. Faecal coliform or *Escherichia coli* (*E. coli*) should be less than 1 bacteria in 100 mL of sample. This is normally written on a laboratory report as <1/100 mL.

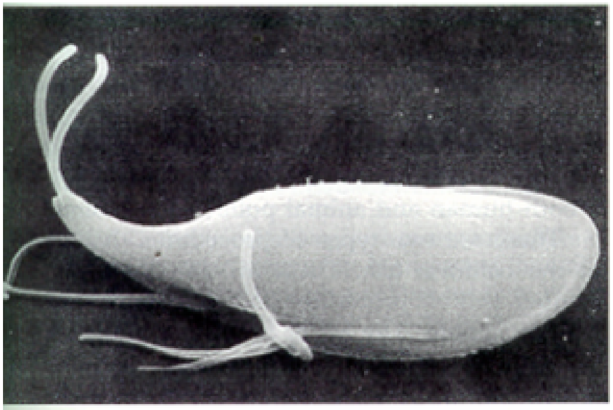
2.2 Viruses



A virus is genetic material (RNA or DNA) in a protein capsule. Viruses are considerably smaller than bacteria, and vary in size from 0.02 to 0.1 micron.

Viruses reproduce by ‘hijacking’ the reproductive system of other cells or host cells. The virus instructs the host cell to reproduce viral genetic material. Then, after many viral units have been manufactured, the host cell is burst open, killing it and releasing the viral particles to spread to other cells. By infecting cells then destroying them, viruses can cause disease.

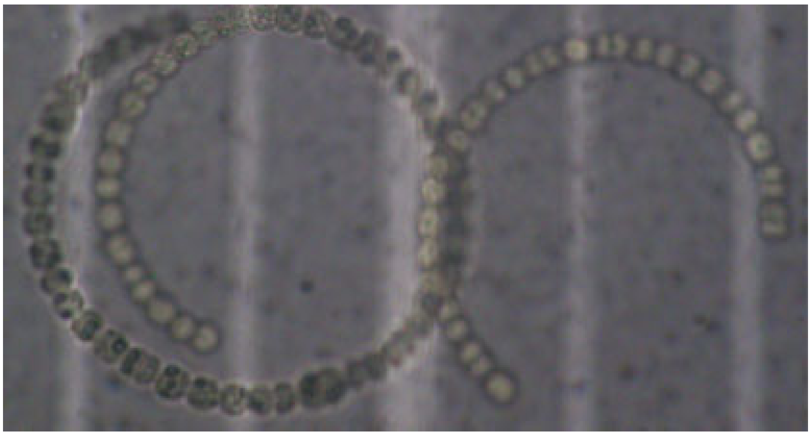
2.3 Protozoa



Protozoa are single-celled microscopic organisms that vary in size between 2 and 70 microns. Protozoa occur mostly in aquatic habitats, such as oceans, lakes, rivers and ponds, from surface water runoff. Groundwater, however, can be contaminated via faults and cracks in the ground allowing in surface water. An aquifer may also be contaminated, through springs or through improperly constructed wells.

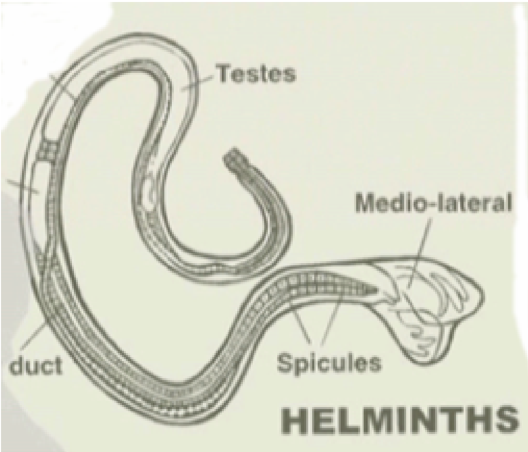
Most protozoa breed by splitting in two, enabling their numbers to increase very quickly, too. However, their reproductive rate is generally not as fast as that of bacteria. Some protozoa have the ability to protect themselves against adverse conditions by forming a **spore** or **cyst** – like the seed of a plant. In this spore or cyst they are able to lie dormant for a long time and, just like seeds, they can withstand drying, extremes of temperature, even poisons.

2.4 Cyanobacteria



Cyanobacteria are aquatic creatures that look like microscopic green plants but are more closely related to bacteria. They grow in colonies and can become a nuisance to water supplies by clogging up filters, giving water a bad taste, and in some cases can release toxins into the water.

2.5 Other micro-organisms: helminths



Technically helminths are not micro-organisms because they can be seen without a microscope. However, because they can affect water quality, they are included here. This category includes intestinal worms and worm-like parasites. Helminth eggs are about 40 microns in size and all stages of their life cycle can be found in most water supplies, especially in surface-water sources that are subject to contamination from human and animal waste.

3 What is a Pathogen?

Put simply, a pathogen (or pathogenic organism) is a disease-causing organism. A disease-causing organism can make you sick.

Even though bacteria, viruses, protozoa and cyanobacteria are tiny, their presence can be felt quite quickly and, if they are pathogenic, they can become a serious threat to the health of a community if they are able to contaminate a drinking-water supply.

Pathogenic micro-organisms generally occur in water supplies that have been contaminated by human and/or animal waste. The ones that affect humans can very quickly multiply inside us and give us **gastrointestinal** illnesses – meaning vomiting and diarrhoea.

4 How do Pathogens Affect the Community?

Gastroenteritis and other gastrointestinal illnesses occur more frequently than many people think. Common causes of waterborne disease include *Giardia* (protozoa), *Shigella* (bacteria), hepatitis A (virus), *Norovirus*, *Cryptosporidium* (protozoa), *Campylobacter* (bacteria), *Salmonella* (bacteria) and *E. coli* (bacteria). (See Table 2 below for more details of these and other causes.) These organisms can be found in faecal wastes (droppings, 'poo' or stool) from a variety of animals (pigs, deer, sheep, cows, birds, possums, etc) and humans. Whether someone will become ill from an infection depends on the **dose** and **virulence** (or toxicity) of the micro-organisms, and the person's resistance to the micro-organisms. The populations most susceptible to waterborne illness are the very young, older people and the sick, especially those with compromised immune systems, including people living with HIV and cancer patients undergoing radiation treatment or chemotherapy.

In most cases of waterborne illness, secondary cases of illness can also occur through the **faecal–oral route**. For example, an infected person will shed the micro-organisms through faeces. If, after using the toilet, this person does not wash his or her hands properly and then prepares food, the food becomes contaminated. Thereafter the micro-organism is transmitted to the person consuming the food, further spreading the disease.

In **some** cases, prolonged exposure to a pathogen can lead to immunity. However, visitors to the contaminated area, who do not have immunity, can still become ill.

Three examples of drinking-water contamination that have affected some communities are outlined below.

- In spring 1984 the water supply to a New Zealand town was contaminated by sewage overflowing from a leaking pump-station. Contaminated water was spread throughout the town. About 3500 people became sick (vomiting and diarrhoea), and a few were hospitalised.
- In March 1986 a rural town in the South Island installed a river-sourced water supply, drawing water via an infiltration gallery – using river gravel to filter water. However, this source was to be chlorinated only as required, when the river was high after heavy rain. When heavy rain fell overnight, the chlorination did not start till 9:00 the following morning, by which time the inlet water contained a high concentration of coliforms. This delay in treating the water was the likely cause of 19 cases of campylobacteriosis.
- In 1997 at a camping ground in rural New Zealand, drinking-water was sourced from shallow bores and had no treatment. During periods of high demand, stream water was observed to backflow into the camping ground's drinking-water supply. Drinking-water became contaminated (95 faecal coliforms per 100 mL). Of 109 camp participants, 67 contracted campylobacteriosis.

Table 2: Common waterborne pathogens

Disease	Micro-organism	Common source	Symptoms
Bacteria			
Verotoxic *E. coli*	*Escherichia coli* O157:H7	Intestines of animals and infected people	Cramping, vomiting, diarrhoea (occasionally bloody), fever, dehydration. Can develop into haemolytic urenemia syndrome
Salmonellosis	*Salmonella typhimurium*	Animals and birds	Abdominal pain, diarrhoea, chills, fever, vomiting and nausea
Typhoid fever	*Salmonella typhi*	Faeces of human typhoid carrier or case	Fever, usually rose spots on the trunk, diarrhoeal disturbances
Paratyphoid fever	*Salmonella paratyphi* (ABC)	Faeces of human carrier or case	Fever, diarrhoeal disturbances, sometimes rose spots on trunk, other symptoms
Shigellosis (bacillary dysentery)	*Shigella*	Faeces of human carrier and infected people	Sudden onset diarrhoea, constant urge to defecate, fever, frequent stools containing blood and mucus
Campylobacter enteritis	*Campylobacter jejuni*	Chickens, swine, dogs, cats, humans, raw milk	Watery diarrhoea, abdominal pain, fever, chills, nausea, vomiting, blood in stools
Cholera	*Vibrio cholerae, Vibrio comma*	Human faeces, vomit; human carriers, shellfish	Diarrhoea, rice-water stools, vomiting, thirst, pain, coma
Legionellosis (Legionnaires' disease)	*Legionella pneumophila*	Aerosols of water that has been stored at warm temperatures	Respiratory symptoms similar to influenza or pneumonic illness
Protozoa			
Amoebiasis (amoebic dysentery)	*Entamoeba histolytica*	Bowel discharges of carrier and infected people; possibly also rats	Diarrhoea or constipation, or neither; loss of appetite, abdominal discomfort; blood, mucus in stool
Cryptosporidiosis	*Cryptosporidium parvum*	Farm animals, human, fowl, cats, dogs, mice	Mild flu-like symptoms, diarrhoea, vomiting, nausea, stomach pain
Giardiasis	*Giardia lamblia*	Bowel discharges of carrier and infected people; dog, possum	Prolonged diarrhoea, abdominal cramps, severe weight loss, fatigue, nausea, flatulence; fever is unusual
Viruses			
Viral gastroenteritis	Rotaviruses, *Norovirus*	Human faeces, or sewage	Nausea, vomiting, diarrhoea, abdominal pain, low fever
Infectious hepatitis	Hepatitis A	Faeces from infected people	Fever, nausea, loss of appetite; possibly vomiting, fatigue, headache, jaundice

5 How do Pathogens Get into Water?

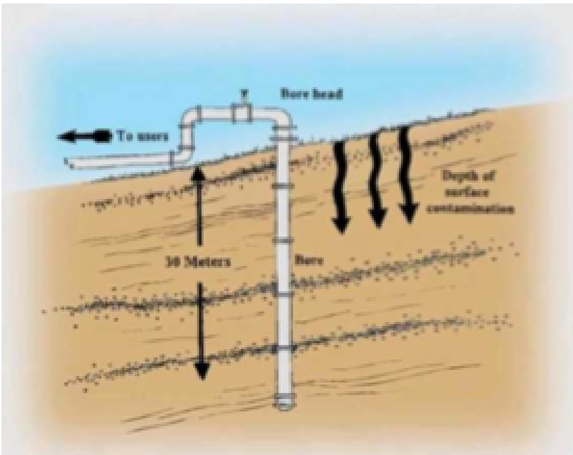
All waterborne pathogens (let's call them 'pathogenic micro-organisms') are transmitted to humans through drinking or otherwise ingesting contaminated water, either directly or via food or poor hygiene. During heavy rain, many of these pathogenic micro-organisms can be washed into waterways, increasing the risk of getting into water supplies.

Therefore, the keys to breaking the process of transmission of these pathogenic micro-organisms are to:

1. protect the water source by preventing contamination from occurring
2. protect the population from ingesting contaminated water by treating a contaminated supply and limiting its use
3. inform the community if something goes wrong.

Examples of how human and animal waste may contaminate a water supply include, but are not limited to the following.

- **Groundwater** may be contaminated through:
  - failure of an on-site sewage disposal system (eg, septic system), which causes direct infiltration to groundwater and/or provides runoff to surface water



  - contamination of the bore or wellhead
  - contamination of shallow well from an offal or dairy-shed waste pit, especially during a drought when groundwater level is low.
- **Surface water** may be contaminated through:
  - discharge of untreated or improperly treated sewage to rivers and reservoirs, including the malfunctioning of waste-water plants during heavy storms with excessive stormwater runoff
  - runoff of animal wastes to surface water from pastures

– over-application of dairy effluent onto pasture, causing contaminated water to run off to surface water and/or infiltrate to groundwater.

- **Roof water** may be contaminated from faeces from possums, birds and cats on roofs from which water is taken. Animals like frogs living in storage tanks can also cause contamination.
- **After treatment** may be contaminated through backflow and cross-contamination into the drinking-water supply.

For more details, see Section 7.

6 How can Contamination be Measured?

Tests have been developed to measure the degree of bacterial contamination in water. The most frequent test is for *E. coli*. These faecal coliforms are organisms that are naturally found in the bowel and lower intestines of warm-blooded animals (including humans). As these places are also the source of many gastrointestinal illnesses, the presence of *E. coli* indicates the presence of faecal contamination and the possible presence of pathogenic organisms. So *E. coli* is used as an indicator organism.

Unfortunately, the absence of *E. coli* does not guarantee that no other micro-organisms are present because *E. coli* are not as hardy as some other micro-organisms. However, they do give a good indication of the safety of a water supply.

To detect the presence of bacteria, you have to grow them in a laboratory, in a process that, of course, takes time – at least 24 hours. A carefully collected sample is first mixed with a special food (media) that will encourage bacteria to grow. Then it is put into an incubator at 35^{o}C for 24 hours. After this time, it will have changed in ways that enable the detection of bacteria – either a colour change, gas production or other evidence. Simple presence/absence (P/A) test kits are available. However, these will only tell you if there are no bacteria, or if there is one or more present; they will not tell you the actual amount of contamination.

For a more detailed test, the sample will have to go a specialist laboratory. To find a laboratory that can do an *E. coli* test, refer to the yellow pages or use online sources: go to http://www.moh.govt.nz/water or http://www.drinkingwater.org.nz/ or search the Internet for ‘Register of Recognised Laboratories Drinking Water Supplies 2006’.

7 Examples of How Pathogens May Get into a Water Supply

The following scenarios illustrate a range of ways in which pathogens can (and do) contaminate a community's water supply.

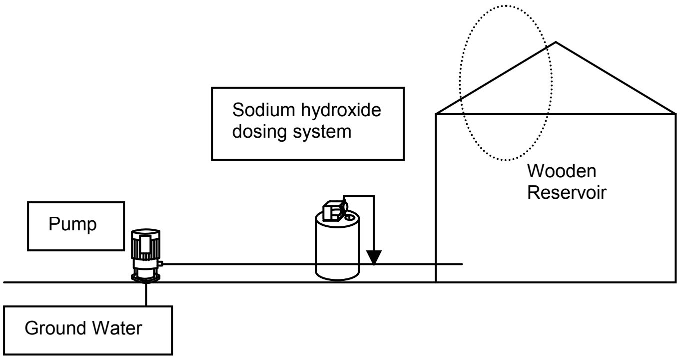
7.1 Damaged storage tank

At a supply serving 50 people, groundwater is abstracted via a deep bore, chlorinated, and then stored in a wooden tank prior to use. Over time, some of the wooden planks that make up the roof of the tank have warped and twisted, allowing gaps to form. In addition, some of these planks rot.

The gap formed allows birds and rats to get into the water, and they start nesting inside the reservoir. Even though the water is chlorinated and the water tested for free chlorine, the contamination is intermittent. Not all of the contamination involves micro-organisms but rather organic matter that causes a chlorine demand – meaning that chlorine gets used up before it can control the micro-organisms in the water.

The operator of the supply notices that there is very little free available chlorine in the distribution system. Then an *E. coli* test shows a positive result of 56 faecal coliforms per 100 mL.

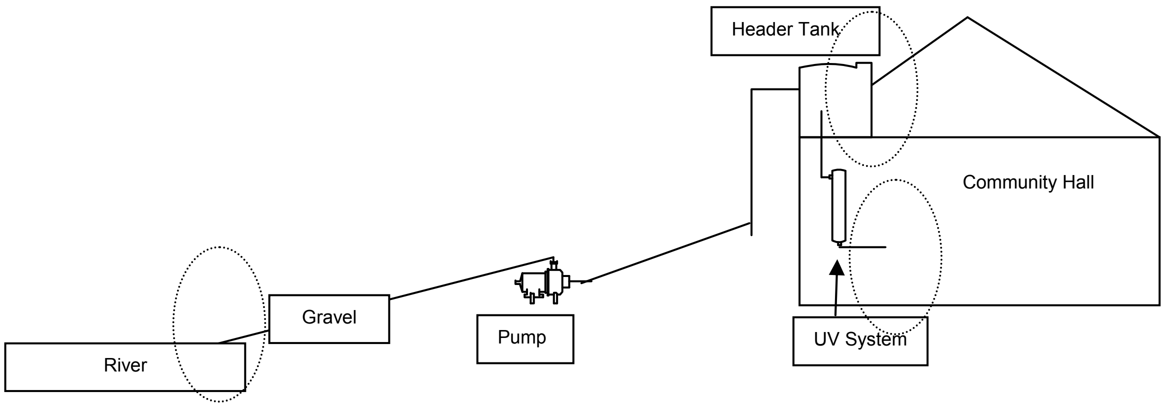
The problem is identified by the testing and fixed before anyone gets sick.



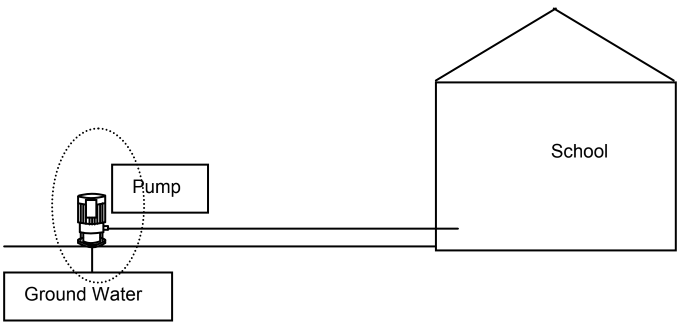
7.2 High turbidity with a UV system

In a small community supply serving 20 households and using a surface water source, a small river flows through lowland pasture with some dairying upstream. The water is pumped out of the river through the gravel (a form of pre-filtration) then disinfected via UV light immediately prior to use.

During high flows, the degree of turbidity and contamination increases, causing poor UV light transmission, meaning that micro-organisms can get past without being inactivated. Users notice the change in water clarity but this cloudiness is a regular occurrence and consumers ‘get used to it’. Then some parents notice that children have diarrhoea after the water has been cloudy. Microbiological tests of the water when it is cloudy show high levels of *E. coli*. Tests of the children show that some of them have campylobacteriosis.



7.3 Damaged well head

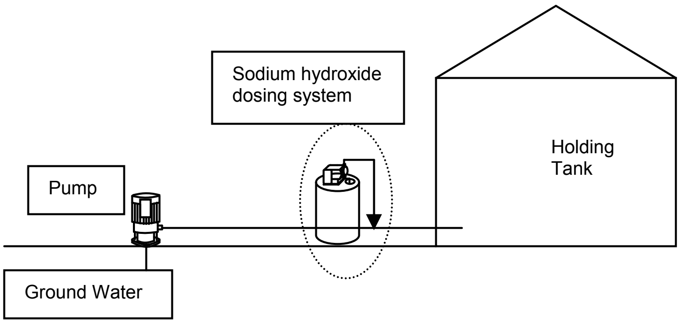


A small school uses a groundwater supply for drinking-water. Clean, safe water is pumped from underground direct to use, without treatment, but the bore is in a paddock that also contains cattle. The well head is not secure due to a hole drilled in the concrete apron, allowing the otherwise safe water to be contaminated with runoff from the paddock. This results in intermittent contamination of the water, after heavy rain. This problem requires immediate action.

Visual inspection would identify this particular problem but the school caretaker does not realise the risks of having an insecure well head.

The water supply comes under suspicion when many of the children are sick with diarrhoea after a period of heavy winter rains.

7.4 Chlorine pump failure



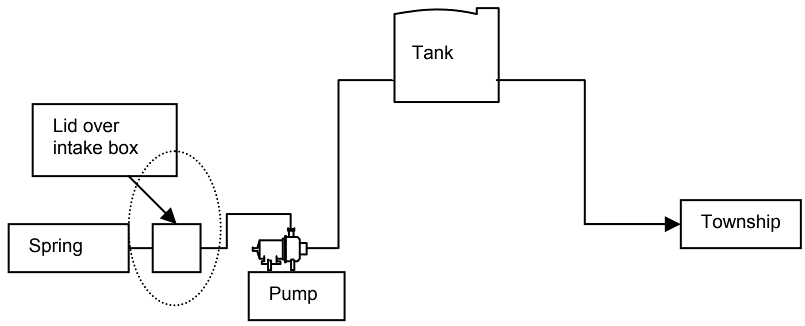
A small community's water is extracted from the ground via a pump, and chlorinated by a dosing pump dispensing liquid chlorine. The water is then stored in a well holding tank prior to use.

As a community collaborative effort to operate the supply, different individuals are on a roster to check the free available chlorine levels and that the treatment plant is running, but some people forget or are not sure what to do. If the chlorine solution runs out or the pump fails to work, or even if chlorine is overdosed, there could be a problem.

The chlorine dosing pump becomes blocked but still makes 'pumping noises'. The chlorine levels drop. The water is from a shallow bore that contains contaminants from farm runoff.

The water supply is contaminated with pathogenic micro-organisms until someone realises the chlorine pump is not working correctly and it is repaired.

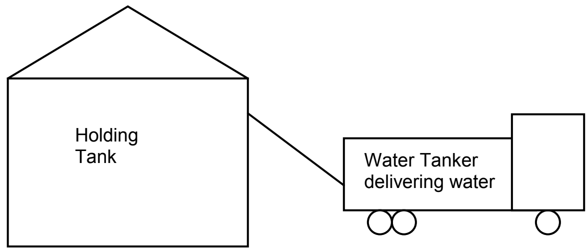
7.5 Spring water with no treatment



Water is supplied via a spring that flows into a covered box, to exclude surface water interference. There is no filtration or disinfection. The springs are situated in lowland bush and there are livestock present in the area. Without the protection of barriers against micro-organisms getting into the water supply, any fault in this system would lead to illness.

Without frequent and regular inspections, some problems could go unnoticed until it was too late. For example, if the lid of the collection box came off, it would allow surface contamination of the otherwise clean spring water.

7.6 Roof water supplemented by tank water delivery



The owner of a roof water supply has to purchase some drinking-water when the household supply runs low during a dry spell.

A worker for a roading company uses the company's water-tank truck to deliver some water during weekends and after hours. During the day, water from a small stream on a farm is used in the truck to wet down dirt on the roading site. After work, the worker fills the truck with water from the town supply without cleaning out its tank first. Some highly contaminated water from the stream is left in the truck, contaminating the load. The water delivered to the house is contaminated. The owner becomes ill with *Giardia*.

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