SOIL SCIENCE AUSTRALIA

Soil in the urban environment

Teacher guide

Resource overview

This is a scenario-based resource is targeted at Year 10 Chemistry but is also relevant to Year 11 Chemistry. Students explore the chemical reactions of pH, salinity, sodicity (dispersion) and corrosion in soil and apply these chemical reactions to a real world scenario.

This resource is divided into five sections. In Part 1, students explore the difference between topsoil and subsoil and use laboratory tests to determine if the topsoil can be re-used in the landscaping of the property development project. Part 2 explores soil sodicity—its chemistry, why it is an issue in construction and strategies for managing soil sodicity.

Parts 3 and 4 may be considered extension work. Part 3 investigates the potential for scaling and corrosion of steel and concrete. Students conduct further laboratory tests and interpret the results to determine if the site is suitable for construction of a new apartment building. Part 4 explores urban soil contamination. Suggested questions and activities for students are provided in Parts 1–4.

The final section, Laboratory methods, explains the tests referred to in Parts 1–4.

Curriculum links

Australian Curriculum Year 10 Science [1]

Science Understanding

Chemical Sciences

Different types of chemical reactions are used to produce a range of products and can occur at different rates (ACSSU187).

Science Inquiry Skills

Questioning and predicting: Formulate questions or hypotheses that can be investigated scientifically (ACSIS198).

Planning and conducting: Plan, select and use appropriate investigation methods, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods (ACSIS199).

[1] Australian Curriculum, Assessment and Reporting Authority [ACARA]. 2016, Foundation to Year 10 Curriculum v8.1: Science. Retrieved from http://www.australiancurriculum.edu.au/science/curriculum/f-10?layout=1 on 10 June 2016.

Introduction

Soil is vital for food and fibre production, supporting plant and animal life, and providing a foundation for infrastructure. Soil science is an integrated science, covering several scientific disciplines including physics, biology, chemistry, ecology and statistics. Although soil science is often coupled with agriculture and food production, many soil scientists work in cities in urban landscaping, water management, property development and land remediation.

Soil management is an important aspect of property development. Developers need to consider if the soil can support their structures, if it will be aggressive to steel or concrete and if it is contaminated. Soil is also used at the end of a development in landscape plantings to provide visual amenity and can add more value to a property.

Before a new development can begin, developers need to strip the topsoil and subsoil to the depth they need to excavate for the building foundations. Often, the soil is simply stripped in one large pile, mixing the topsoil and the subsoil. This is because, traditionally, only geotechnical soil testing is undertaken rather than soil fertility testing. However, it is beneficial to try and keep the topsoil separate to re-use in landscape plantings. This saves project money as the existing soil doesn't need to be trucked off site (as is the norm) and new soil doesn't need to be purchased and trucked in.

Scenario

You are a property developer looking to construct a new apartment block in your city. Use the information provided and suggested laboratory tests to decide:

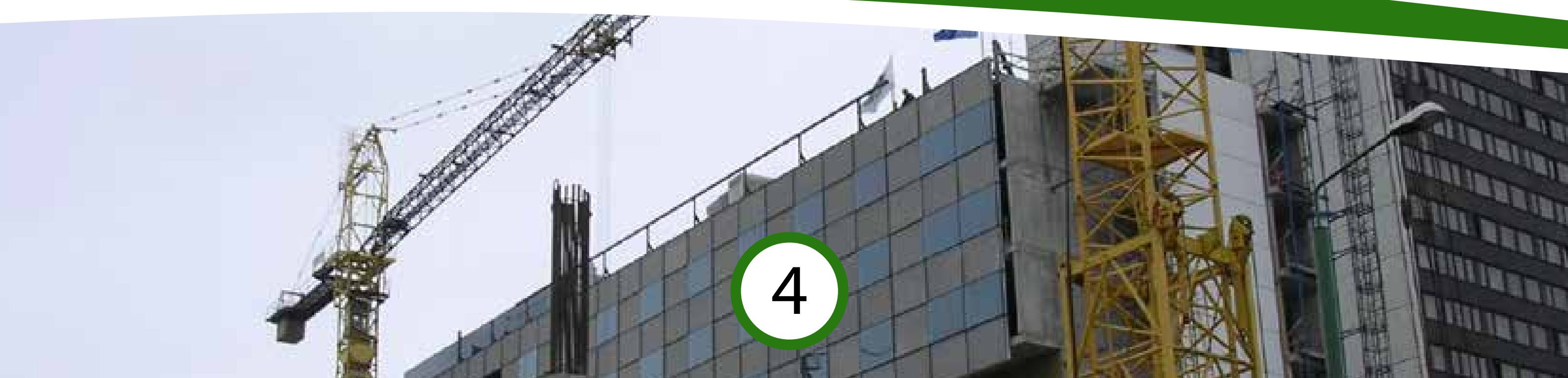
- Part 1: Can you keep the existing site topsoil to use in the landscape plantings or will you need to buy new soil?
- Part 2: Will erosion and dispersion be a problem on your site during excavation?

Extension section

After completing Parts 1 and 2, students can explore whether the subsoil will be aggressive to their new building structure (Part 3).

Assume the soil is suitable for your development. You begin excavating, only to find a buried underground fuel storage tank. The tank has been leaking into the surrounding soil. What contaminants have leaked into the soil and are they likely to have reached the groundwater?

You will need samples of different soil—a topsoil and subsoil sample—ideally collected from your school yard. If the school soil is very sandy, try to collect a clay sample from elsewhere to use as the subsoil and for comparison purposes.



Part 1—Understanding the soil on site

Background information

This section explains the difference between topsoil and subsoil and the factors that determine if a topsoil is suitable for landscape plantings.

Students test basic chemical parameters (pH, electrical conductivity, texture, dispersion and organic matter) to determine if the topsoil is suitable to re-use in the landscape plantings or if it needs to be removed.

Soil

Topsoil is the surface layer of soil where most nutrients, organic matter, soil organisms and plant roots concentrate. Topsoil is generally more fertile and tolerable to living organisms than subsoil. In construction projects, it is ideal to test the topsoil and preserve it for future use in landscape plantings. This saves money and minimises waste as the purchase of new soil is not required and the existing topsoil does not need disposal. Quite often, existing site topsoil is of better quality than soil that is purchased from a landscaping yard. Landscaping yard soil often lacks useful minerals and can decompose in a few years.

The amount of topsoil varies from location to location but is typically from the surface to 20 cm in depth.

Subsoil is the soil beneath the topsoil. There may be only one or several different subsoil layers before hitting rock at depth. Subsoil is often heavier in texture i.e. it has more clay and can have chemical characteristics that make it toxic to plant roots. Some subsoils are highly acidic or sodic and, where possible, are best left buried. Other subsoils are fertile and can easily support plant growth; hence it is essential to test the quality of the subsoil before making any construction or project decisions.

Soil texture

Soil texture is the 'feel' of a soil and can be very simply classed as sand, loam, or clay. It describes the amount of sand, silt and clay in a soil. A 'sandy' soil will be mostly sand and a 'clayey' soil mostly clay. Soil texture is important because it influences other soil properties such as:

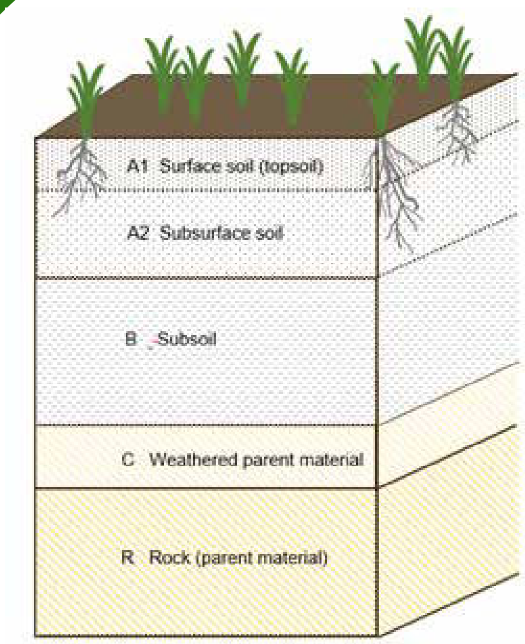


Figure 1. A soil profile.

- water holding capacity: soils with more clay can hold more water than sandy soils
- nutrient holding capacity: soils with more clay can hold more nutrients
- compaction: sandy soils are less susceptible to compaction than clay soils
- drainage: sandy soils drain better and are less prone to waterlogging than clay soils.

To determine a soil texture, refer to Test 1 in the Laboratory methods.

Soil Colour

Colour is a very distinctive feature and may be diagnostic of other soil properties. It provides a useful indication of soil drainage, the degree of leaching and the organic matter content. Colour is mainly due to the presence of iron oxides and organic matter. Organic matter consists of darkly coloured compounds which, if present in any quantity, tend to mask the colours of iron oxides. The presence of manganese oxides also darkens the soil.

In a few soils the colour is derived directly from weathered rock. For instance, red and yellow colours are both caused by iron oxides. Red indicates good drainage and aeration, while yellow usually indicates a damper and less well aerated soil. Grey often indicates impeded drainage. Bleached (near white or white) subsoil layers are indicative of seasonal saturation and intense leaching of organic matter. Mottles (specks or spots of colour different from the matrix colour) commonly indicate soils that are poorly drained with periodic waterlogging.

Humus (highly decomposed organic matter) darkens any soil, so topsoils are usually darker-coloured than subsoils.

Table 1. What soil colour indicates about other soil properties

	Black/dark	Pale	Red/brown	Yellow	Grey/blue grey
Drainage	Often slow	Well drained	Well drained	Less well drained	Poorly drained
Waterlogging potential	Medium	Low	Low	Low-medium	High
Organic matter accumulation	High	Low	Medium-high	Medium-high	Low

pH

pH tells you how acidic or alkaline something is. The lower the pH the more acidic it is and the higher pH the more alkaline it is. For instance, lemon juice has pH around 2, pure water has a pH of 7 and household bleach has a pH of 9.

In soil, pH chemistry is simply the balance between hydrogen and hydroxyl ions. The higher the concentration of hydrogen ions the more acidic the soil; the greater the concentration of hydroxyl ions the more alkaline the soil. A pH of 7 is considered neutral.

pH is important in soil science because it affects the availability of nutrients. In acidic soil conditions, iron, aluminium and hydrogen become very available (i.e. soluble), while most other nutrients are limiting. In alkaline conditions, sulfur, potassium, calcium, magnesium and boron are highly available, while nitrogen, iron, manganese, copper, phosphorus and zinc are limiting.

To test the pH of the soil, refer to Test 2 in the Laboratory methods.

Electrical conductivity (salinity)

Salinity is a measure of how salty a soil is. The more salts there are, the more 'saline' a soil is. Soil salinity is measured by dissolving the salts in the soil in water and measuring the electrical conductance of that water extract. This number is the electrical conductivity (EC) and is reported in units of deci-siemens per metre (dS/m) or in the older units milli-siemens per centimetre (mS/cm) or millimhos per centimetre (mmhos/cm).

High salt levels can adversely affect plant growth, soil structure, water quality and infrastructure.

To obtain the conductivity of the soil water extract, the EC must be multiplied by the texture factor. Instructions for testing EC and texture factors are provided in Test 3 in the Laboratory methods section.

Dispersion (sodicity)

See Part 2 below.

Organic matter

Organic matter is the remains of once-living things (animals, leaves, flowers, fruit, insects, sticks), as well as living organisms such as fungi, bacteria, nematodes and worms. Soil organic matter is the food for the soil ecosystem and food for plants. Organic matter forms when plant parts and animals die and start to decompose.

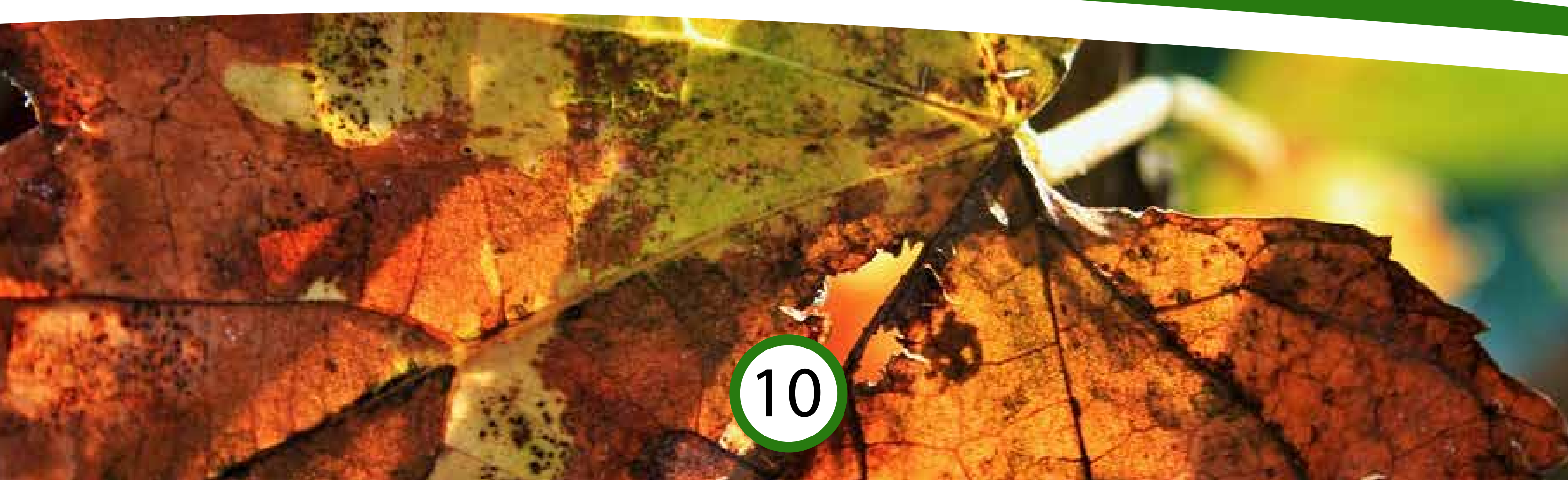
Old leaves and branches die and fall to the forest floor where microbes, fungi and bacteria break down the plant material. This is recycling at its finest––turning death back into life.

A soil is generally comprised of 50–60% mineral (the 'soil' part), 25% pore space, 15% water and 5–8% organic matter. Soils can have anywhere from 1–50% organic matter but a level of around 5% is considered average in natural Australian topsoils.

Soils need organic matter because it:

- improves water infiltration
- decreases evaporation
- improves water-holding capacity
- reduces surface crusting
- encourages root development
- improves soil aggregation
- helps prevent compaction
- provides nutrients to plants
- is food for soil organisms
- increases the nutrient holding capacity of the soil.

It is difficult to test organic matter levels outside a professional laboratory. If you have the resources, you can send your topsoil samples to a laboratory for analysis. Ask them to test organic carbon and organic matter levels.



Soil fertility

A fertile soil is one which has ample nutrients in an available form and organic matter to support the plants growing in it.

A soil fertility analysis is usually conducted by a laboratory. There are some simple home soil test kits (e.g. Lusterleaf Rapitest Soil Test Kit) to analyse nitrogen, phosphorus and potassium levels. These kits can be ordered online.

Activities and questions

1. Students research soil properties such as soil colour, fertility, texture, soil horizons (layers), soil structure, pH and EC. Ask students to explain each property and how they affect plant growth (e.g. pH is a measure of acidity/alkalinity. It affects plant growth as a too high or too low pH makes nutrients unavailable for plant absorption. The plant then becomes deficient in these nutrients).

2. Students prepare a plan for assessing soil quality on the development site. They should consider:
   a. Where they will take soil samples and why they chose these locations. (Soil scientists often sample in a grid pattern across a site and take extra samples if the vegetation looks different or if there are bare patches etc.).
   b. How they will take soil samples i.e. what equipment will be used?
   c. What safety measures should be considered and how you manage these issues? E.g. underground services—use Dial Before You Dig (see below) and don't dig next to lights or electrical boxes.
   d. What tests they will conduct on the samples and what equipment they need to do these tests. Refer to the parameters outlined in Question 1 above and tests outlined in the Laboratory methods section at the end of this guide.
3. Designate a site on the school grounds as the development site. Complete a 'Dial Before You Dig' (DBYD at <http://www.1100.com.au>) to ensure you aren't digging near any services. Check with the groundskeeper to locate irrigation lines and that you aren't digging on the sports field playing surface.

4. Dig a hole in the school grounds to about half a metre or to about 20 cm after you can see a change in the soil that indicates different layers. Use an auger or a shovel. These layers will be loosely classified as the 'topsoil' and 'subsoil' i.e. the surface layer is the topsoil, while the second layer is the subsoil.
5. Collect samples from the topsoil and the subsoil. You should collect about 500 grams per group of four students.
6. Measure the depth of the topsoil. How deep does it go? Record the depth.
7. Record whether the soil is damp or dry.
8. Record the presence of rocks or other material. Some urban soils are made from 'fill': leftover soil from other areas or developments. Fill usually has a large amount of rocks or gravel and even tiles and glass in the worst cases.
9. Using the Laboratory methods at the end of this guide, ask students to test the texture, colour, pH, and salinity (EC) of the topsoil and subsoil and record the results.
10. Students to compare results between the topsoil and subsoil. What is different? What is similar?
    Using their research on soil properties, students discuss how the soil properties of the soil they analysed might affect plant growth. For example, nutrient availability can be affected by soil pH (more information can be found at www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf)
11. Based on this analysis, students decide if the topsoil should be reused when it is time to install the landscaping or if it should be disposed of. If the soil is to be reused, how deep should the excavator dig when stripping the topsoil? (The excavator should ideally remove the topsoil and put it in one pile, then the subsoil and put it in another pile. Subsoils often have chemical issues so it's best the topsoil and subsoil aren't mixed).

Extension

12. Students research other soil characteristics they might test for when checking the quality of a soil for planting? (Nutrients, cations, permeability)
13. What do these properties tell us about a soil and how do they affect plant growth?
14. Assume you have a topsoil that has a pH of 4.5 and is too acidic for healthy plant growth. What product would you use to raise the pH and what is the chemical reaction that takes place? (Less than ideal soil properties can often be ameliorated. For example, an acidic pH can be corrected using lime. A sodic soil (see Part 2 of this guide) can be ameliorated using gypsum).

Liming materials raise pH by displacing hydrogen (H+) from the clay particles. It is the hydrogen ion (H+) that makes soils acid. The displaced hydrogen then reacts with carbonate (from the lime) and forms carbonic acid. Carbonic acid is not stable in soils and quickly forms carbon dioxide and water.

H^+(attached to clay) + lime ($CaCO_3$) $\longrightarrow$
Ca^{2+}(attached to clay) + carbonic acid (H_2CO_3)

Then: carbonic acid (H_2CO_3) $\longrightarrow$ water (H_2O) + carbon dioxide (CO_2)

Part 2—Exploring sodicity and dispersion

This section explores the important topics of soil sodicity, salinity and salts.

Background information

Before exploring soil sodicity, students should also understand salts and soil salinity as the three concepts are interrelated.

Salt

A salt is a compound that is formed when an acid is neutralised by a base. The name of a salt has two parts: the first is the name of the positive ion, the second is the negative ion. The salt most people are familiar with is table salt—sodium chloride (NaCl). This is a combination of sodium (positive ion) and chloride (negative ion). Other salts include ammonium nitrate, potassium chloride, calcium carbonate and many others.

Salinity

A saline soil has an excess of salts in the soil solution. Salinity can occur when irrigating with saline water, by land clearing or mineral weathering. Salts occur naturally in soil but if they accumulate, the soil becomes more saline.

High levels of salinity can be toxic to plants resulting in a lack of groundcover. Reduced groundcover makes a soil more susceptible to erosion which results in topsoil loss, waterway pollution and damaged ecosystems. In agriculture, soil salinity decreases crop yields. In construction, excess salinity can corrode infrastructure such as building foundations and roads. This topic is explored further in Part 3.

To test for salinity, refer to Test 3 in the Laboratory methods.

There are a few options for improving soil salinity. You can 'flush' the soil with clean water to wash the salts from the profile. However, this method is far less effective in a clay soil compared to a sandier soil because water filters more slowly through the clay and the salts are held more tightly to the soil particles.

Another option is to plant salt tolerant species that will absorb some of the salts. In some areas, soil salinity has been caused by irrigation or removing trees. Irrigation adds water to the subsoil and watertable. As a result, the underground watertable rises, bringing salts towards the surface. Tree clearing removes the deep root systems, which previously used the underground water. This tree removal can also result in the watertable rising and bringing salts towards the surface.

Sodicity

Sodicity is an excess of sodium ions attached to soil minerals. Soil sodicity causes problems including dispersion, hardsetting, erosion and contamination of waterways. In agriculture, sodic soils can impede crop growth and limit yields. In construction, soil dispersion can result in erosion and the washing of sediments (and attached pollutants) into waterways. During construction, runoff from areas of disturbed dispersive soils contain large amounts of clay and can be very cloudy. Once in waterways, it is difficult to remove the clay without using products such as alum (aluminium sulfate). In the waterways, the clay reduces light levels, lowers water quality and can harm aquatic life.

If not managed, dispersive subsoils can form underground drainage paths (i.e. tunnel erosion) that causes the surfaces such as roads to collapse.

How sodicity works

A sodic soil has excessive amounts of sodium ions attached to soil minerals and clay particles. Clay particles are negatively charged and are bound together into aggregates (peds) by positively charged ions—cations. The major soil cations are sodium, calcium, magnesium and potassium.

A schematic representation of these cations and the soil's exchange complex is shown for a non-saline, non-sodic soil in Figure 2.

The formation of stable soil aggregates is called flocculation. Flocculation encourages water infiltration and root growth, and it minimises soil erosion and surface crusting. Sodium (Na^+) is a weak flocculant, whilst calcium (Ca^{2+}) and magnesium (Mg^{2+}) are strong flocculants. Calcium and magnesium work like a glue to hold soil particles together, creating a stronger soil structure.

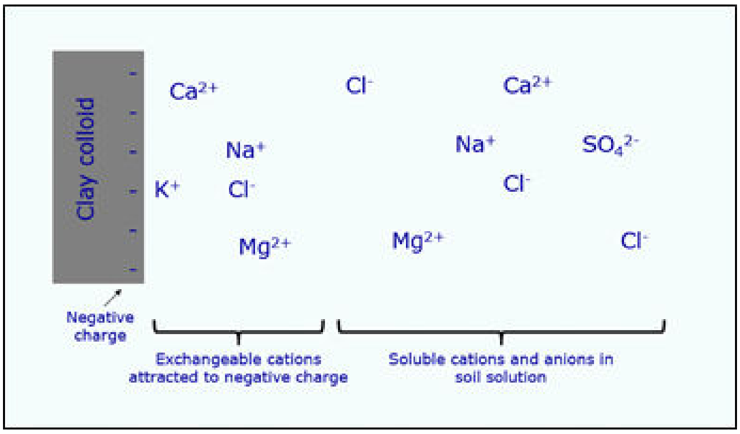


Figure 2.
A non-saline and non-sodic soil: schematic representation of the negatively charged soil surface (cation exchange capacity) being balanced by an excess of exchangeable cations and deficit of anions at the surface of the particle.

In a sodic soil, there are less calcium and magnesium cations and more sodium ions attached to the soil particles. When the soil is exposed to water—such as from irrigation or rainfall—the sodium particles act like two positive ends of magnets—they repel each other and form a layer of clay at the surface. The soil swells and the clay particles disperse, causing the soil structure to decline and collapse. The dispersed clay blocks soil pores and, when it dries out, forms a hard seal at the surface. This seal means water cannot penetrate and runs off, leading to erosion.

This separation of the clay particles is known as dispersion. Soils that disperse have an unstable structure. Dispersion is affected by soil texture, organic matter levels, soil salinity and exchangeable cations. Dispersion causes the water around the soil to become cloudy.

Signs of a sodic soil include:

- erosion, high run-off and low infiltration rates, surface ponding and poor aeration
- severe surface crusting, slaking or collapsible soils
- sodium (Na) levels greater than 6% of the total cations in a soil test, expressed on a percentage charge basis
- soils that disperse (show cloudiness) when dropped into a dish of rainwater or deionised water.

To test for sodicity and dispersion, refer to Test 4 in the Laboratory methods.

Salinity vs sodicity

The difference between salinity and sodicity is:

- a saline soil: the sodium and other salts are soluble and freely moving about the soil solution (Figure 3).
- a sodic soil: there is a high proportion of sodium ions at the clay particle surface, which weakens the bonds between soil particles when the soil is wetted.

Soils can be sodic without being saline (Figure 4), however most saline soils are also sodic (Figure 5).

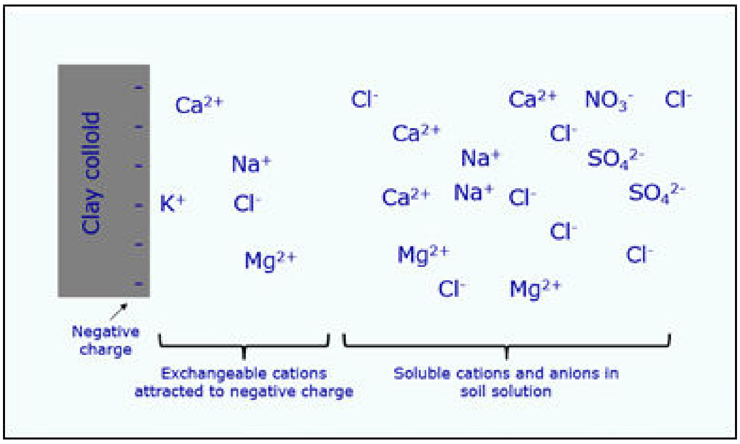


Figure 3.
A saline, non-sodic soil: schematic representation of the excess soluble salts in the soil solution.

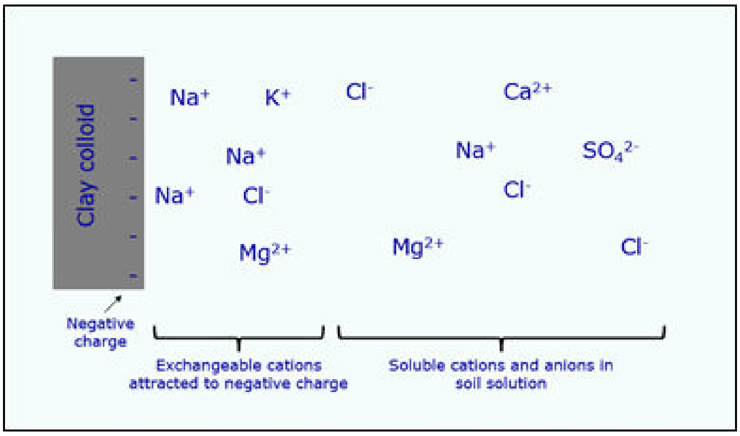


Figure 4.
A non-saline, sodic soil: schematic representation of the negatively charged clay colloid with a high proportion of sodium (Na^+) ions attracted to the soil surface.

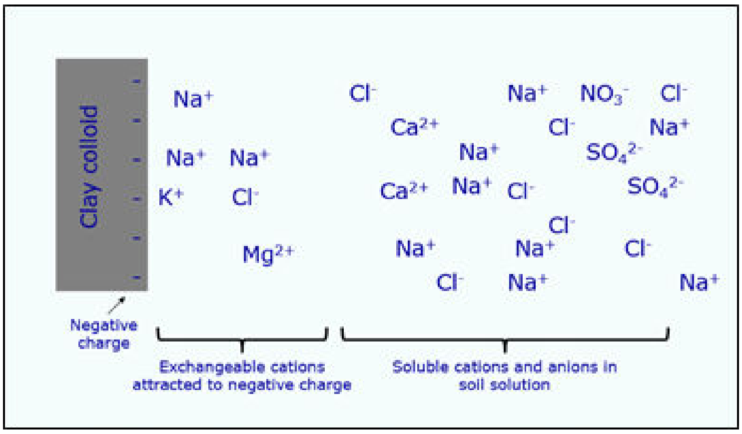


Figure 5.
A saline, sodic soil: schematic representation of the soluble salts present in the soil solution and a high proportion of sodium ions at the clay particle surface.

Testing for sodic soil

The best way to ameliorate a sodic soil is to replace the sodium ions in the soil with calcium.The most widely used calcium soil additive is gypsum (calcium sulfate dihydrate—$CaSO_4.2H_2O$). Gypsum is used because it is inexpensive, soluble and non-toxic. Gypsum works by supplying calcium ions which displace the sodium ions and allow the clay particles to glue together again. The displaced sodium ions are displaced into the soil solution and can be washed away.

Sodium (attached to clay) + gypsum $\longrightarrow$
calcium (attached to clay) + sodium ions (in solution) + sulfate ion

$$2Na\ (Clay) + CaSO_4 \longrightarrow Ca\ (Clay) + 2Na^{+} + SO4^{2-}$$

Gypsum will only really be effective on sodic clays. It will do little to improve soil structure on clays that are not sodic or soils that have small amounts of clay.

Lime can also be effective in reducing sodicity but only if the soil pH is below 6.0. Lime is usually calcium carbonate ($CaCO_3$) or dolomitic lime (a combination of calcium carbonate and magnesium carbonate). When lime is applied to an acid soil, the carbonate ion (from lime) & hydrogen ion (from the soil) combine. The end products from this reaction are water (H_2O) and carbon dioxide (CO_2). Calcium is now attached to the exchange site and the hydrogen ion is liberated. Less hydrogen means a higher (less acidic) soil pH.

$$H(Clay)H + CaCO_3(Limestone) \longrightarrow Ca(Clay) + H_2CO_3(Carbonic\ Acid)$$
Then: $H_2CO_3 \longrightarrow H_2O\ (Water) + CO_2(Carbon\ Dioxide)$

Lime is relatively insoluble above a soil pH of 6 and hence cannot dissolve to exchange calcium ions for sodium ions.

Lime raises the pH of a soil, but gypsum won't.

Note: it is very difficult to ameliorate a sodic subsoil when it is in situ. Doing so requires stripping off the topsoil, incorporating the ameliorant and watering in. Additionally, subsoils are often clayey and the low permeability means reducing the sodicity is even more challenging. Where possible, sodic subsoils should be left buried and undisturbed.

Some soils are naturally high in calcium carbonate (CaCO3) and are called 'calcareous' soils. You can test for the presence of carbonates by putting a drop of dilute acid on the soil and observing whether or not there is any effervescence. Effervescence occurs when the acid reacts with the calcium carbonate to product carbon dioxide (CO2) bubbles as shown in the following reaction with sulfuric acid and hydrochloric acid:

Sulfuric acid + calcium carbonate $\longrightarrow$
carbon dioxide gas + water + calcium ion+ sulfate ion

$$H_2SO_4 + CaCO_3 \longrightarrow CO_2(gas) + H_2O + Ca^{2+} + SO4^{2-}$$

Hydrochloric acid + calcium carbonate $\longrightarrow$
carbon dioxide gas + water + calcium ion+ chloride ions

$$2HCl + CaCO_3 \longrightarrow CO_2(gas) + H_2O + Ca^{2+} + 2Cl^{-}$$

Activities and questions

1. Explain verbally what soil salinity and soil sodicity are. Using Figures 2 and 3 as an example, students interpret and draw:
   a. A sodic soil
   b. A saline soil
   c. A sodic and saline soil
2. Students research and discuss why soil sodicity and soil salinity are problems. Look up images to see how salinity and sodicity can affect a landscape.
3. Test for dispersion in the topsoil and subsoil or the different soil types you have collected (Test 4 in laboratory methods).
4. Record results and determine if either the topsoil or subsoil are likely to disperse during construction works. Assume the topsoil and subsoil are both dispersive. What do you think will happen once the vegetation is cleared and there is rainfall?
5. Based on your result, is the topsoil or subsoil likely to erode? Assume the soil is sodic and therefore likely to erode. What are the possible consequences of erosion on your site? (e.g. Sediments could be washed into stormwater drains and waterways).

Extension

6. If the soil is dispersive, amend with gypsum (using rates such as 50g, 100g, 150g etc.) and leave for a couple of weeks. You need to set up the experiment so the soil is in a container with holes at the bottom for water to leach out. Add the gypsum to damp soil, mix thoroughly and water the soil a couple of times over the course of the experiment. Re-test for dispersion every week. The soil needs to be able to drain to give the sodium a chance to leach out. Changes should be evident in three to four weeks.
7. Test the salinity (Test 3) and dispersion again after a few weeks. What chemical reactions occurred with the addition of gypsum? What chemical products have been produced?
8. Research and discuss why gypsum works at most soil pH's but lime will only work if the soil is acidic.
9. Discuss why gypsum initially raises the salinity of the soil solution. What effect would this have on plants? (Because the gypsum forces sodium off the soil particles and into the soil solution, soil salinity rises after gypsum addition. With irrigation or rainfall, the soil salinity will drop again after a few weeks).
10. Assume the subsoil on your development site is sodic (dispersive). Research sodic subsoil management techniques and develop a plan to manage the subsoil throughout construction. A good starting point is often government or Department of Main Roads websites e.g. http://dpipwe.tas.gov.au/Documents/DPIW_DSM_Manual_April2009.pdf

Part 3—Corrosion (Extension)

Aggressive soil can corrode concrete and steel: the foundations of a building. In this section, students conduct a simple aggressivity analysis to investigate if the subsoil on site will corrode the foundations of their building.

Background Information [2]

Aggressiveness is the propensity of a soil or water to dissolve concrete structures. The degree of aggressiveness depends on the types of ions present. Different ions will cause either physical expansion or a loss of cementing properties, reducing concrete strength. The permeability of concrete to air and moisture is the main factor influencing resistance to aggression.

With a reduction of the porosity and moisture content of the soil, there is also a reduction in the degree of aggressiveness, as aggressive materials in the soil and gases can only develop their effect if there is sufficient moisture available.

Corrosion of metals is an electrical phenomenon. Salts in water themselves have no direct role in corroding metal; rather, they promote electrical conductivity. Therefore, a wet environment high in oxygen and high in chemical ions is the most corrosive. A highly saline soil with high oxygen levels is highly corrosive, but the same salinity deep in a soil profile with less oxygen is less corrosive.

The major factor in the corrosion of metals is the electrical conductivity (EC) of the surrounding soil solution or water. The EC can be greater in sandy soils than in clayey soils, and is greater in salt water than in fresh water.

[2] Sources: SESL Australia , http//www.sesl.com.au ; Mountain Empire Community College http://water.me.vccs.edu

Resistivity measures how well a soil resists the flow of electricity. The higher the resistivity, the better a soil can resist electricity flow, and the less likely that soil is to be corrosive to steel. Resistivity is the inverse of conductivity (Table 2).

An ion is an atom or molecule with a positive or negative charge. This charge stems from the atom/molecule either losing or gaining electron(s).

Hydroxide (OH-) is a compound consisting of an oxygen and hydrogen atom held together by a covalent bond. Hydroxide is a constituent of water.

Soil resistivity (ohm cm)	Corrosion Rating
> 20,000	Essentially non-corrosive
10,000 – 20,000	Mildly corrosive
5,000 – 10,000	Moderately corrosive
3,000 – 5,000	Corrosive
1,000 – 3,000	Highly corrosive
< 1,000	Extremely corrosive

The corrosiveness of a soil or wet environment towards metals and its aggressiveness towards concrete structures can be estimated by chemical and physical tests including pH, salinity, soil texture, sulfate, chloride and resistivity.

The two things that affect concrete structures the most are acidity and sulfate, both of which chemically eat away at the cement matrix.

Alkalinity, hardness, and pH interact to determine whether water will produce scale or corrosion or will be stable. Table 3 summarises characteristics of corrosive water and of scale-forming water.

Table 3. Characteristics of corrosive and scale forming water

Corrosive Water	Scale-forming Water
• low pH	• high pH
• soft or with primarily non-carbonate hardness	• hard with primarily carbonate hardness
• low alkalinity	• high alkalinity

Generally, corrosion is the result of water with a low pH. Acidic waters have lots of H+ ions in the water so corrosion is enhanced. In contrast, water with a higher pH lowers the solubility of calcium carbonate so that the calcium carbonate is more likely to precipitate out as scale.

Activities and questions

1. What are ions?
2. What are oxides and hydroxides?
3. Students to write or discuss: What is corrosion? Why might corrosion be a problem in your development?
4. Test the sulfate levels of the soil filtrate and the tap water and record your results. See Test 5 in the Laboratory methods.
5. Test the chloride levels of the soil filtrate and the tap water and record your results. See Test 6 in the Laboratory methods.
6. Using the data you have collected, the proposed resistivity value of 1,500 ohm.cm and the Tables 4 and 5 below, determine if the soil is likely to cause corrosion of concrete or steel.
7. What happens to your results if resistivity is 800 ohm.cm? What if it was 8,000 ohm.cm? How does this change your overall results?
8. Using the data collected on the tap water (pH, EC, sulfate, chloride), is this water likely to cause scaling or corrosion? If not, what chemical characteristic would it need to have to do so?

9. What chemical reactions are happening during scaling and corrosion?
    a. What products are made from these reactions?
    b. How does temperature affect these reactions?

Table 4.

Uncoated steel piles in soil (Exposure classification)

pH	Chlorides (ppm)		Resistivity (ohm.cm)	Electrical Conductivity (dS/m)	Drainage -Texture Relationship	Exposure Classification
	Soil	Groundwater				
>5	<5,000	<1,000	>5,000	<0.2	Coarse textured soil (e.g. gravel or sand) that is very well drained; Coarse textured soil that is somewhat poorly drained; or Medium textured soil that is well drained.	Non-aggressive
4-5	5,000 - 20,000	1,000 -10,000	2,000 -5,000	0.2 -0.4	Fine textured soil that is well drained; Medium textured soil that is somewhat moderately well drained; or Very poorly drained soil with a high water table.	Mild
3-4	20,000 - 50,000	10,000 - 20,000	1,000 -2,000	0.4 -1.0	Fine textured soil that is moderately well drained; Medium and fine textured soil that is somewhat poorly well drained; or Very poorly drained soil with a water table fluctuating to within 30cm of surface.	Moderate
<3	>50,000	>20,000	<1,000	>1.0	Fine textured soil that is poorly or very poorly drained; or Peat soils with a fluctuating water table	Severe

Adapted from the United States Department of Agriculture Soil Survey Staff 1971, Guide for Interpreting Engineering Uses of Soils, US Government Printing Office, Washington DC, cited in Miller et al. 1981, Soil Surveys for Corrosion Assessment, STP741-EB/Aug1981; and from the Australian Standard 2159:2009 Piling—Design and Installation

Table 5
Concrete piles in soil (Exposure classification)

pH	Sulfates (SO_4^{2-}) In soil (ppm)	Sulfates (SO_4^{2-}) In groundwater (ppm)	Chlorides in groundwater (ppm)	Drainage -Texture Relationship	Exposure Classification
>5.5	<5,000	<1,000	<6,000	Coarse textured soil (e.g. gravel or sand) that is very well drained; Coarse textured soil that is somewhat poorly drained; or Medium textured soil that is well drained.	Mild
4.5 -5.5	5,000 - 10,000	1,000 -3,000	6,000 -12,000	Fine textured soil that is well drained; Medium textured soil that is somewhat moderately well drained; or Very poorly drained soil with a high water table.	Moderate
4-4.5	10,000 - 20,000	3,000 - 10,000	12,000 -30,000	Fine textured soil that is moderately well drained; Medium and fine textured soil that is somewhat poorly-well drained; or Very poorly drained soil with a water table fluctuating to within 30cm of surface.	Severe
<4	>20,000	>10,000	>30,000	Fine textured soil that is poorly or very poorly drained; or Peat soils with a fluctuating water table	Very Severe

Adapted from Pritchard, Oliver et al. 2013, Soil corrosivity in the UK—impacts on critical infrastructure. Retrieved from http://www.itrc.org.uk/wp-content/PDFs/Soil-corrosivity-impacts-UK-infrastructure-report.pdf on 16 June 2016; and from the Australian Standard 2159:2009 Piling—Design and Installation

Part 4—Underground fuel tank (Extension)

Background Information

Soil contamination is principally caused by the presence of man-made chemicals or other alterations in the natural soil environment. Soil contamination is a cause for concern because of:

- human health risks (direct contact with contaminants, contaminant vapours generated in the soil and secondary contamination of water supplies)
- ecological risks
- remediation costs. Once the soil contamination reaches a point where it's considered a risk, it can be expensive to remediate or 'clean up' the site.

Examples of common chemicals involved in soil contamination from human industry are:

- heavy metals
- fertilisers high in nitrogen and phosphorus
- petroleum hydrocarbons—constituents of oil, petrol and diesel
- solvents
- organochlorine and organophosphate pesticides e.g. cattle dips
- cyanides from mining.

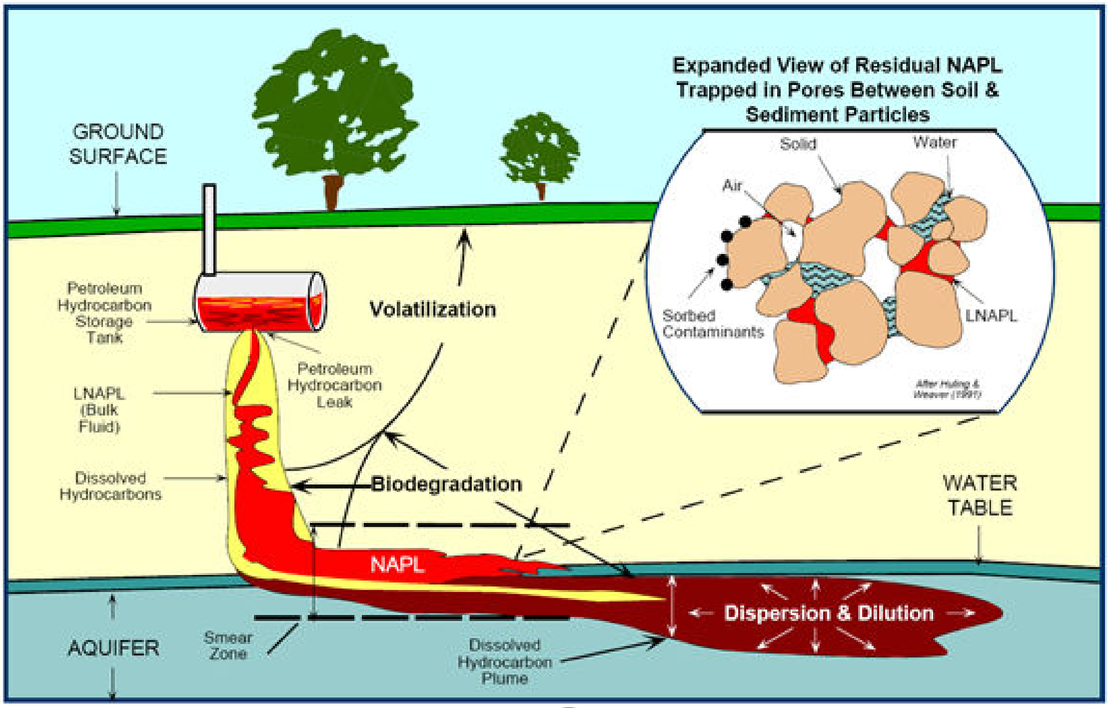
Underground tank installation

Underground storage tanks are installed in a pit surrounded by sand and/or gravel. If the tanks leak, the contaminants move into the surrounding soil. If the soil surrounding the pit is a clay, it will hold the contaminants in a 'bath tub' scenario. If, however, the surrounding soil is sandy, the contaminants can leach further down the soil profile and into groundwater.

Contaminants such as hydrocarbons can:

- volatilise—gaseous forms of a contaminant can fill air spaces in pores in the soil, creating a toxic environment
- dissolve into pore water
- sorb (or bind to) to soil particles

Figure 6.
The fate of an unleaded fuel spill (Source: US EPA 'Monitored Natural Attenuation of Petroleum Hydrocarbons' Remedial Technology Fact Sheet May 1999)
NAPL = Non-aqueous phase liquids



Figures 7 & 8. An underground fuel tank being removed.

Activities and questions

1. What sorts of fuels could be stored in the tanks on your site?
2. What are the contaminants of unleaded, leaded and diesel fuel?
3. Why are these products considered contaminants?
4. Research ways to ameliorate soil contamination. What are the chemical reactions that take place during amelioration? Suggestions: Hydrolysis, substitution, elimination, oxidation, reduction, biodegradation.
5. Write some examples of chemical reactions that occur during soil amelioration.
6. Further investigation reveals that your underground tank was storing unleaded fuel. Design an amelioration strategy to clean up the soil on your site. The strategy should include the order in which you will do the tasks (e.g. remove tanks, excavate soil).

Useful references

Dragun, J. 1998, *The Soil Chemistry of Hazardous Materials* 2nd Edition, Amherst Scientific Publishers.

Alloway, B.J. 1995, *Heavy Metals in Soils* 2nd Edition, Springer.

Yong, R.N., Mulligan, C.N. 2004, *Natural Attenuation of Contaminants in Soils*, Lewis Publishers.

NSW EPA 2013, *Service station sites: assessment and remediation*.
Available from: http://www.epa.nsw.gov.au/mao/servicestation.htm

US EPA 2015, *EPA's Superfund Program.*
Available from:
http://www.epa.gov/superfund/students/wastsite/soilspil.htm

Laboratory methods

The following laboratory methods were adapted from the Queensland Department of Natural Resources and Water 2007, Tool Kit: for identifying subsoil constraints in Australia's northern grains regions. Used with permission of The State of Queensland (Queensland Department of Science, Information Technology and Innovation).

Preparing filtrate for analysis
Method

1. Soil samples need to be air-dried by placing them on a clean plastic sheet in a dust-free area. Crush large soil aggregates to less than 2 mm in size. Remove any rocks or plant residues.
2. Prepare 1:5 soil:water suspension by weighing 20 g air dry soil and add 100 mL distilled water or rain water to a lidded container.
3. Shake suspension for 5 minutes.
4. Stand suspension for 2 minutes.

At this point, use the pH and EC meters to measure the pH (Test 2) and EC (Test 3) of the solution.

5. Filter the 1:5 soil:water suspension through filter paper
6. Save the clear filtrate for the sulfate and chloride tests (Tests 5 and 6).

Step 3

Step 4

Test 1—Soil Texture

Equipment

•A handful of soil
•Water
•Ruler

Method

1. Fill palm of the hand with soil and moisten with deionised water to make a ball about 4 cm in diameter.
2. Keep adding small amounts of water until the ball (bolus) starts to stick to your hand. Record the feel of the soil while working with it.
3. Make a ribbon by squeezing the ball between thumb and finger. Record the length of the ribbon when it breaks.
4. Estimate the soil texture and organic matter content use the table below.

Step 1

Step 2

Step 3

Table 4.
Soil texture descriptions

Soil texture	Description	Ribbon length (mm)	Approximate clay content (%)
Sand	Very little or no coherence. Cannot be rolled into a stable ball. Individual sand grains adhere to the fingers.	5–10	<10
Sandy loam	Fine-medium sand can be felt. The bolus is gritty.	15–25	10–20
Loam	Soil ball is easy to manipulate and has a smooth spongy feel. Fine sand can be felt	25–40	20–30
Clay loam	Plastic like soil, capable of being moulded into a stable shape. No obvious sand grains	40–50	30–35
Light clay	Firm to strong, smooth and silky feel.	50–85	35–45
Medium clay	Feels like plasticine.	85–100	45–55
Heavy clay	Very strong, smooth plastic feel. Can be hard to work in your hand.	100+	>55

Figure 9.
Example ribbon lengths of different soil textures

Particle size analysis

Another way to estimate the texture of a soil is to do a particle size analysis. These are normally done with a variety of sieve sizes; however you can do a rough estimate using a handful of soil and a glass jar.

1. Half fill the jar with soil
2. Add water until the jar is almost full. Leave about 5 cm air space at the top.
3. Screw the lid on tightly and shake vigorously for a few minutes. You are trying to break up any soil clumps (peds).
4. Leave the jar and wait for the sediment to settle.

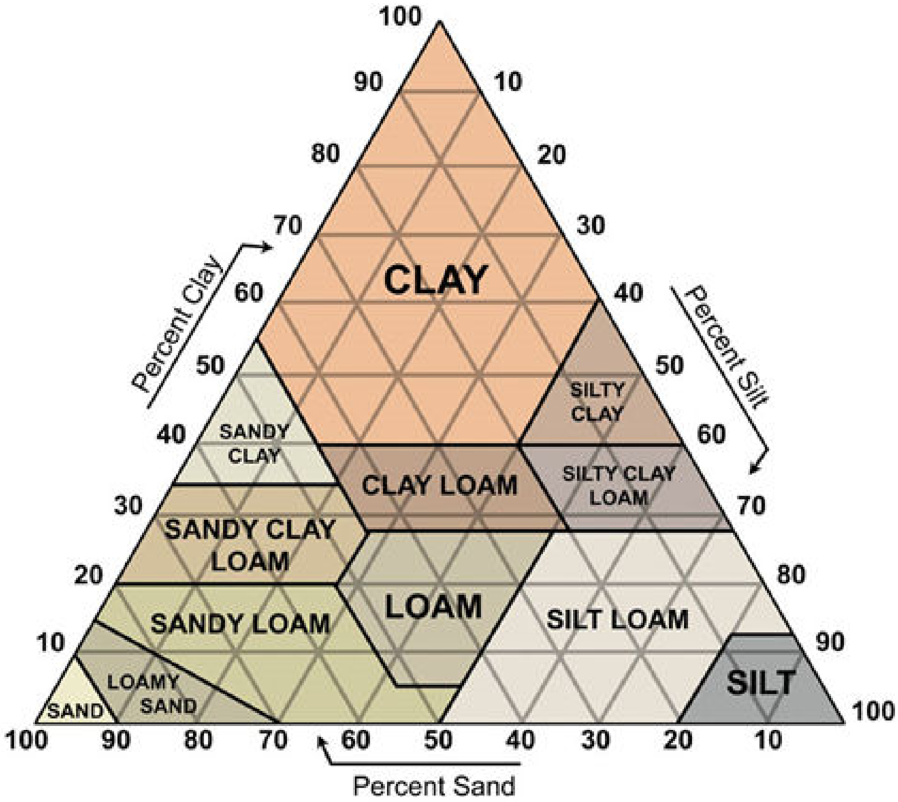
The sediment will settle with the largest grains (sand) at the bottom, and the smallest particles (clay) at the top. You can use the soil texture triangle below to estimate the soil texture.

Step 1

Step 4

The above PSA example soil is about 50% coarse sand (bottom layer), 35% (middle layer), and 15% clay (top layer). The water at the top hasn't cleared yet indicating there is some very fine clay that is still to settle. Note: it takes about six hours for silt to settle and clay can take days.

Figure 10.
Soil texture triangle



Retrieved from:
www.qld.gov.au/environment/land/soil/soil-properties/texture
on 13 June 2016.

Test 2—pH

Equipment

- pH meter or kit
- Soil water (prepared by 1:5 soil solution––see 'Preparing the filtrate' at the beginning of the Laboratory methods)

Method

Using the pH meter, measure the pH of the soil solution and some tap water.

If a pH meter is not handy, measure the pH using pH paper or red cabbage leaves. Instructions can be found at http://www.abc.net.au/science/surfingscientist/pdf/lesson_plan16.pdf

You can also purchase a pH test kit from a gardening store. These kits use barium sulfate and an indicator solution to determine soil pH. If using these kits, you don't need the soil water filtrate.

Table 5

Interpreting pH values

pH	Interpretation
<4.5	Extremely acidic
4.5 –5.0	Very strongly acid
5.1 –5.5	Strongly acid
5.6 –6.0	Moderately acid
6.1 –6.5	Slightly acid
6.6 –7.3	Neutral
7.4 –7.8	Mildly alkaline
7.9 –8.5	Moderately alkaline
8.5 – 9.0	Strongly alkaline
> 9.0	Very strongly alkaline

Test 3—Electrical Conductivity (EC)

Equipment

- EC meter
- Soil water (prepared by 1:5 soil solution––see 'Preparing the filtrate' at the beginning of the Laboratory methods)

Method

Note: you will need to know the texture of your soil to finish this exercise.

1. Using the EC meter, measure the EC of the soil solution and some tap water
2. Record your results, and use Table 6 below to convert the EC reading into a soil salinity reading. You need to multiply the EC reading by the conversion factor to calculate is the electrical conductivity of the extract (ECe).

Table 6

Soil texture and salinity conversion factors[3]

Soil Texture	Conversion Factor
Sands	17
Loams	10
Clay Loams	9
Light Clays	8
Medium Clays	7

[3]Slavich, P.G. and Petterson, G.H. 1993, Estimating the critical conductivity of saturated paste extracts from 1:5 soil:water suspensions and texture, Australian Journal of Soil Research, 73-81.

Table 7

Soil salinity interpretation[4]

ECe* (dS/m)	Comment
<2	Not saline
2–4	Slightly saline
4–8	Moderately saline
8–16	Saline
>16	Highly saline—too saline for most plant species

Example: A 1:5 EC of 0.4 dS/m on a loam soil (conversion factor 10) gives a salinity (ECe) reading of 4 dS/m (0.4 * 10).

Test 4—Dispersion

Equipment

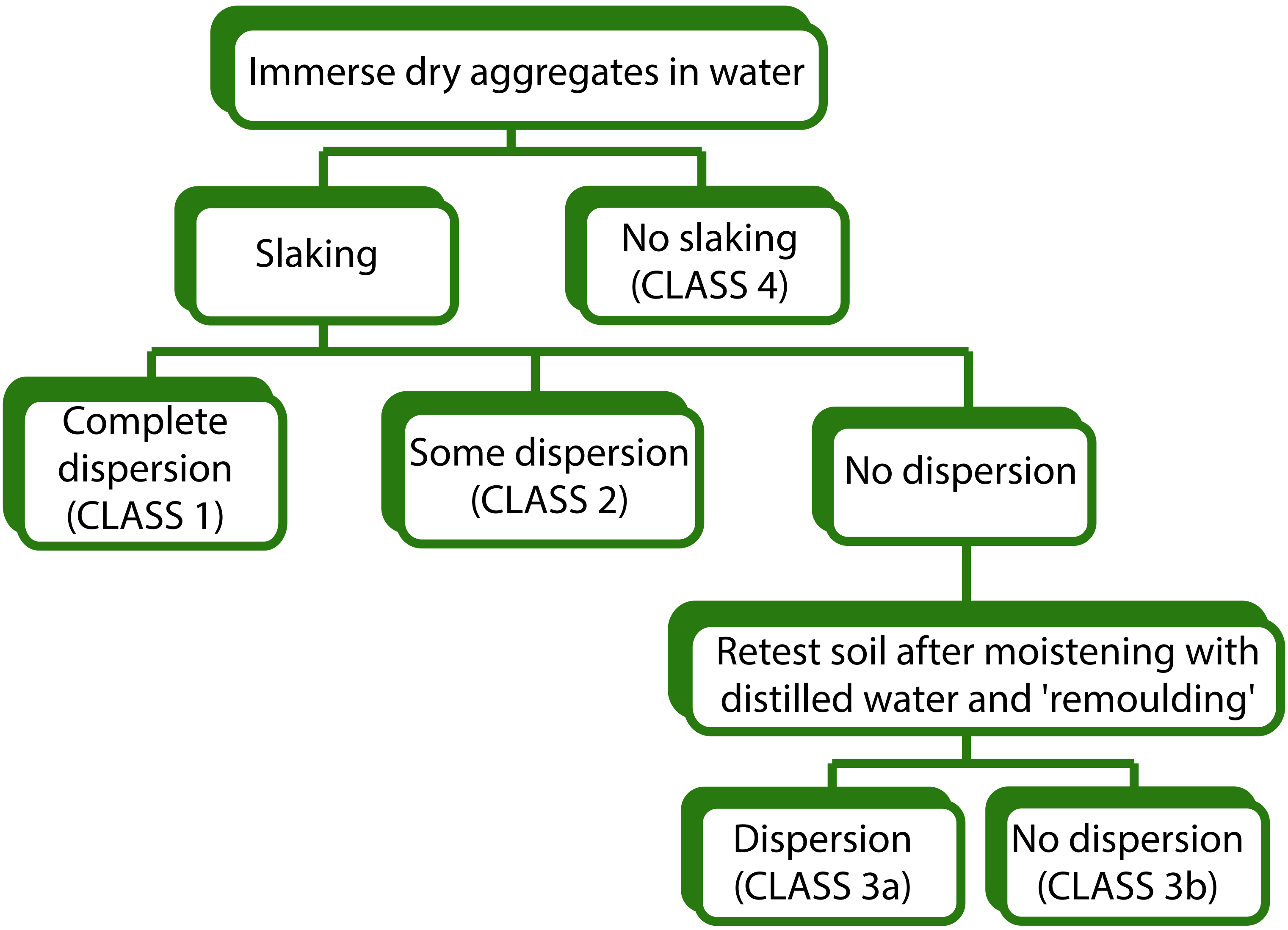
- Three soil aggregates (about 3–5 mm in diameter) from each soil type
- Petri dishes
- Deionised water

Method

1. Fill each petri dish about three-quarters full with deionised water.
2. Place three soil aggregates from each soil type in the dish i.e. put three peds from Soil 1 in Petri dish 1, and three peds from Soil 2 in Petri dish 2.
3. After 10 minutes, record the dispersion category and again after two hours.

[4] Taylor , S. 1991, Dryland salinity introductory extension notes, Department of Conservation and Land Management, NSW.

If the peds simply collapse, they have slaked and not dispersed. Slaking is when a lump of soil (ped) breaks down into smaller fragments upon wetting. It happens when clay inside a ped swells when exposed to water and air inside the ped bursts out, causing the ped to collapse. A soil with a high organic matter content is less likely to slake as the organic matter binds the particles together and slows the rate of wetting.



CLASS 1: A thin cloud covers the bottom of the dish and the aggregate appears as a small heap of sand. This soil may suffer from severe crusting, erosion and poor drainage.

CLASS 2: A cloud of dispersed clay surrounds the aggregate and usually spreads in thin streaks on the bottom of the dish. These soils may have problems similar to CLASS 1 soils but not as bad.

CLASS 3a: Dispersion occurs only after the aggregates have been remoulded. The remoulding simulates management practices such as cultivating or compacting the soil when wet. If these practices are avoided, dispersion is also avoided.

CLASS 3b: Slaking (but no dispersion) has occurred. This is a favourable result, although slaking alone could still lead to problems.

CLASS 4: If the aggregates remain intact they are stable and the soil is in good condition.

Slaking, minimal dispersion

Slaking and dispersion

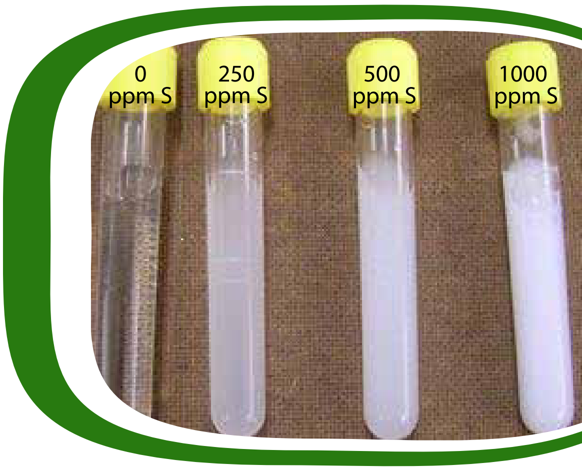
If the water around the soil goes cloudy, the soil is dispersing. The cloudier the water, the more dispersion has occurred and the more sodic the soil is.

Test 5—Sulfur

Important: You'll be using barium chloride (1M BaCl2) which is toxic.
Use protective gloves. Avoid contact with skin or eyes.
If contact occurs, wash thoroughly.

Method

1. Take 3 mL of clear filtrate in a test.
2. Add 2 mL of barium chloride using disposable pipette. If the solution quickly turns milky white, this indicates the presence of sulfur (S) in the soil.
3. Record the category of the milky water.



3 mL filtrate +
2 mL barium chloride

None	(0 mg S/kg)
Slightly milky	(250 mg S/kg)
Medium	(250 mg S/kg)
Very milky	(500 mg S/kg)

Test 6—Chloride

Important: You'll be using silver nitrate (1M AgNO3), which is toxic and can be fatal if swallowed. If swallowed seek medical advice immediately. Avoid contact with skin or eyes. If contact occurs, wash thoroughly.

Method

1. Take another 3 mL of the clear filtrate in a test tube
2. Add 2 mL of silver nitrate using disposable pipette. If the solution turns milky white immediately, this indicates the presence of chloride (Cl) in the soil. Soon it will form a white precipitate which will settle down at the bottom of the test tube.
3. Record the extent of the precipitate.

3 mL filtrate +
2mL silver nitrate

0 ppm 200 ppm 500 ppm 1000 ppm

None	(0 mg Cl/kg)
Small amount	(200 mg Cl/kg)
Medium	(500 mg Cl/kg)
Large precipitate	(1000 mg Cl/kg)

SOIL SCIENCE
AUSTRALIA