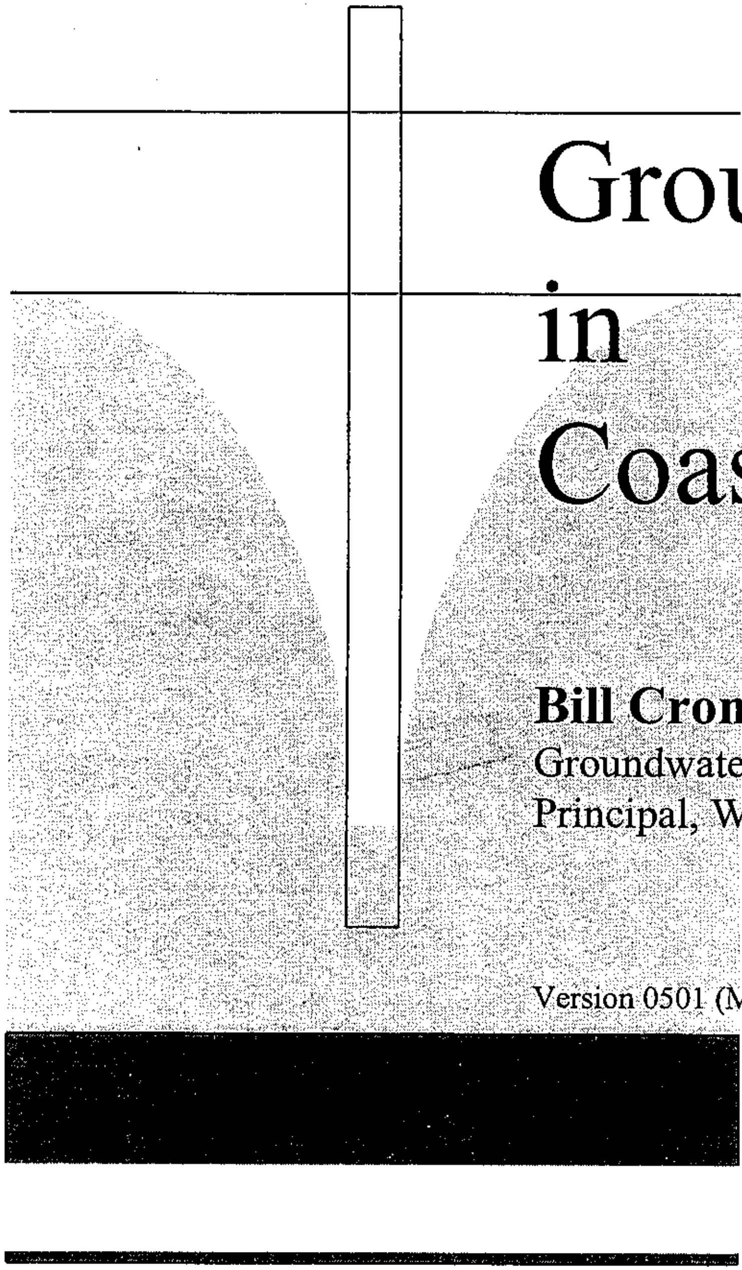

Groundwater in Coastal Sands

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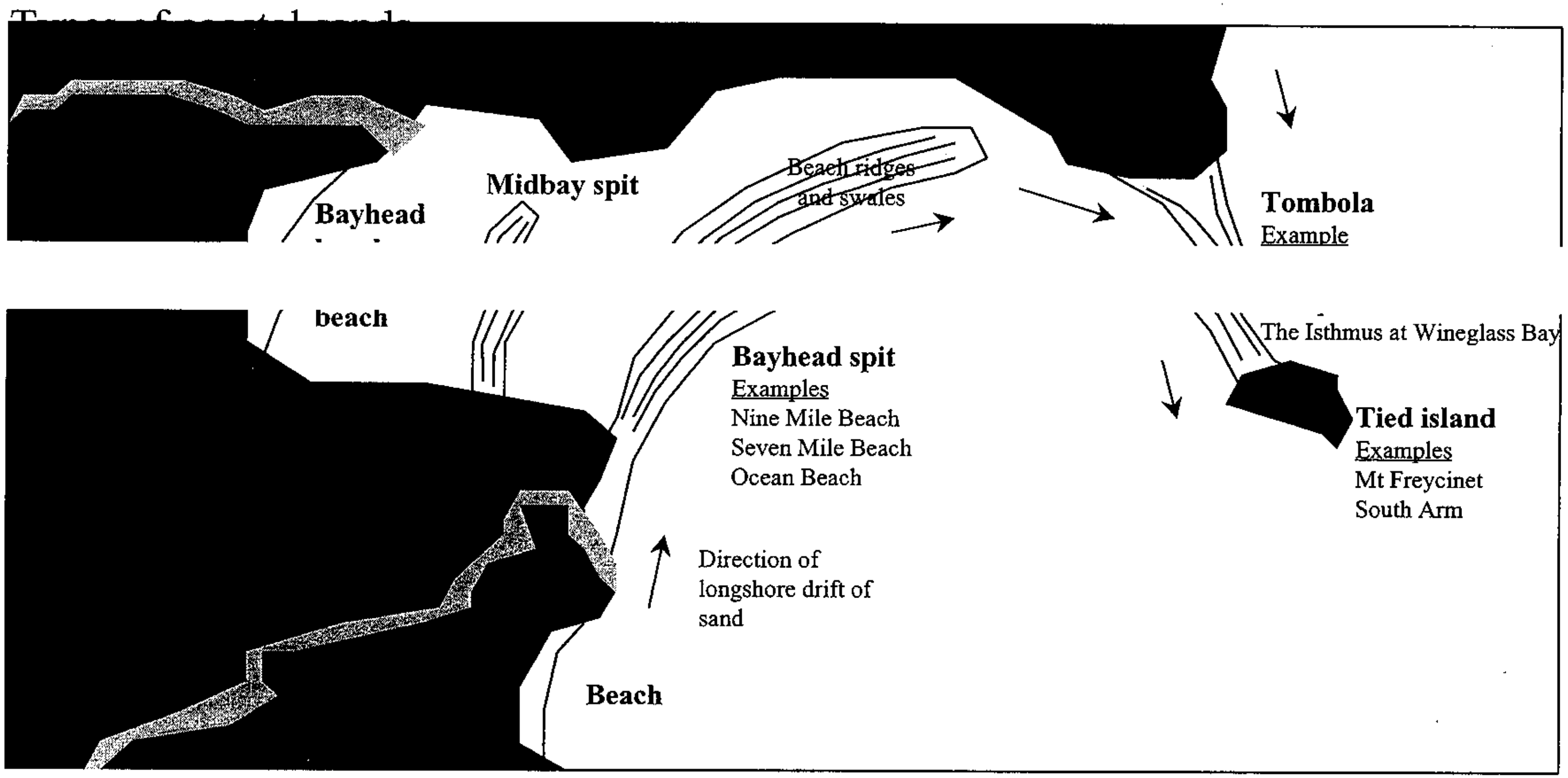
What are "coastal sands"?

Coastal sands are of course restricted to coastal areas, and are generally low-lying bodies of sand formed mainly by wave action. They include beaches, spits and tombolasof all sizes, from small features a few tens of metreslong, up to beach or spit systems hundreds ofkilometres long. Typically, they are much longer than wide, and much wider than thick.



Bayhead spit used as an example

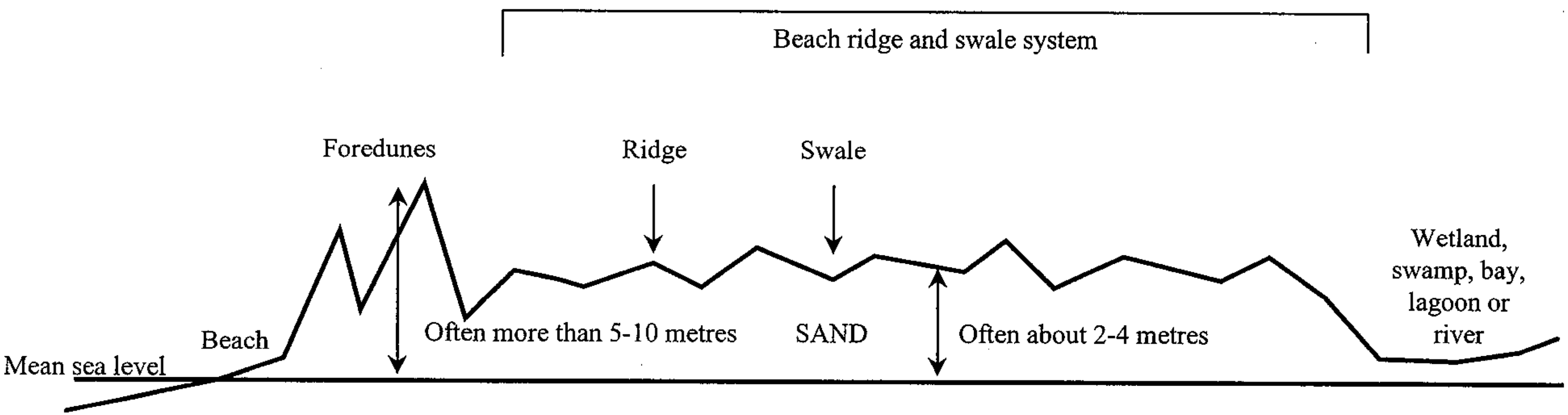
This presentation discusses groundwater in coastal sands using a bayhead spit (or simply, a spit) as an example.

Most of the hydrogeological principles apply equally to all other coastal sand bodies.

Main features of a typical spit

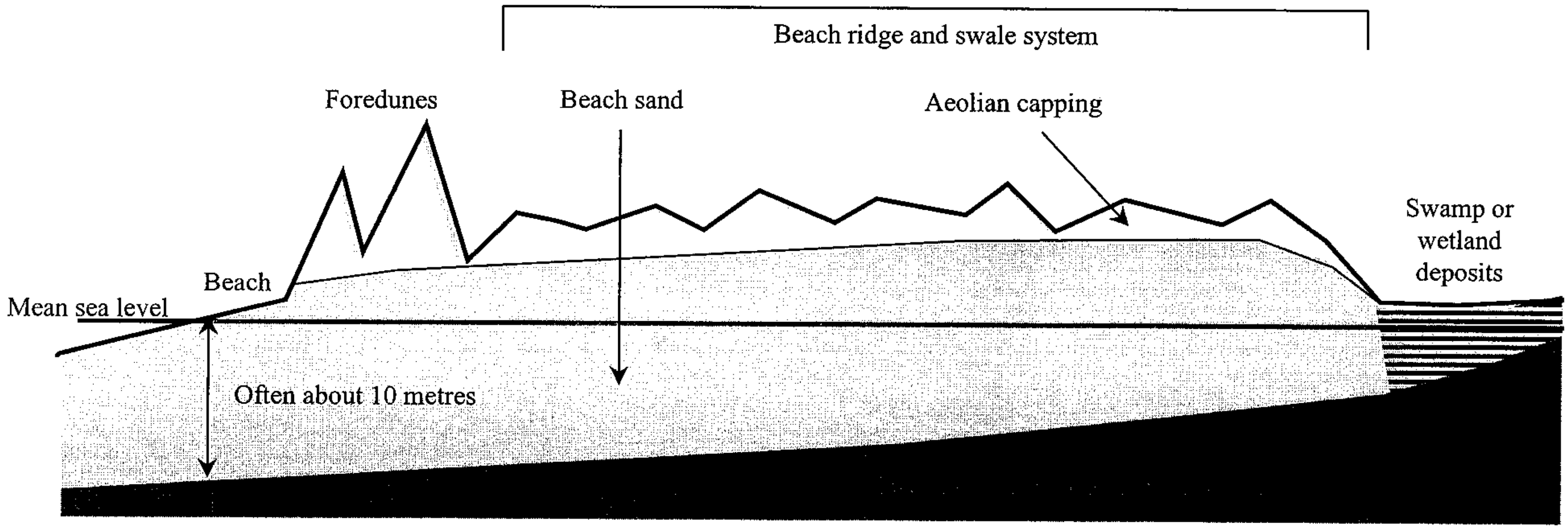
Spits usually comprise, from the coast inland, a beach, one or two foredunes and a ridge and swale system, usually backed by a low lying swamp, wetland, bay or river. The height difference between a ridge and adjacent swale typically ranges from about 0.5 to 2 metres. The beach ridge system is often only about 2 to 4 metres above mean sea level. Foredunes may be 5 to 10 metres high , and sometimes much more.

Cross section through a typical spit



Geological cross section of a typical spit

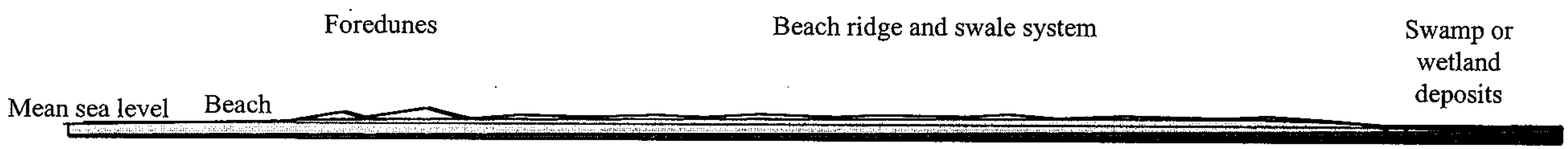
Spits typically consist of beach sand overlying a clay base, and covered with a veneer of aeolian (wind-blown) sand. The beach sand is often shelly. The clay base dips seawards, usually about 10metres below sea level.
The cross section below is vertically exaggerated many times.



Geological cross section of a typical spit at natural scale

This is the same cross section as the previous slide, but with the vertical scale squeezed to something approaching the horizontal scale. This is a natural scale.

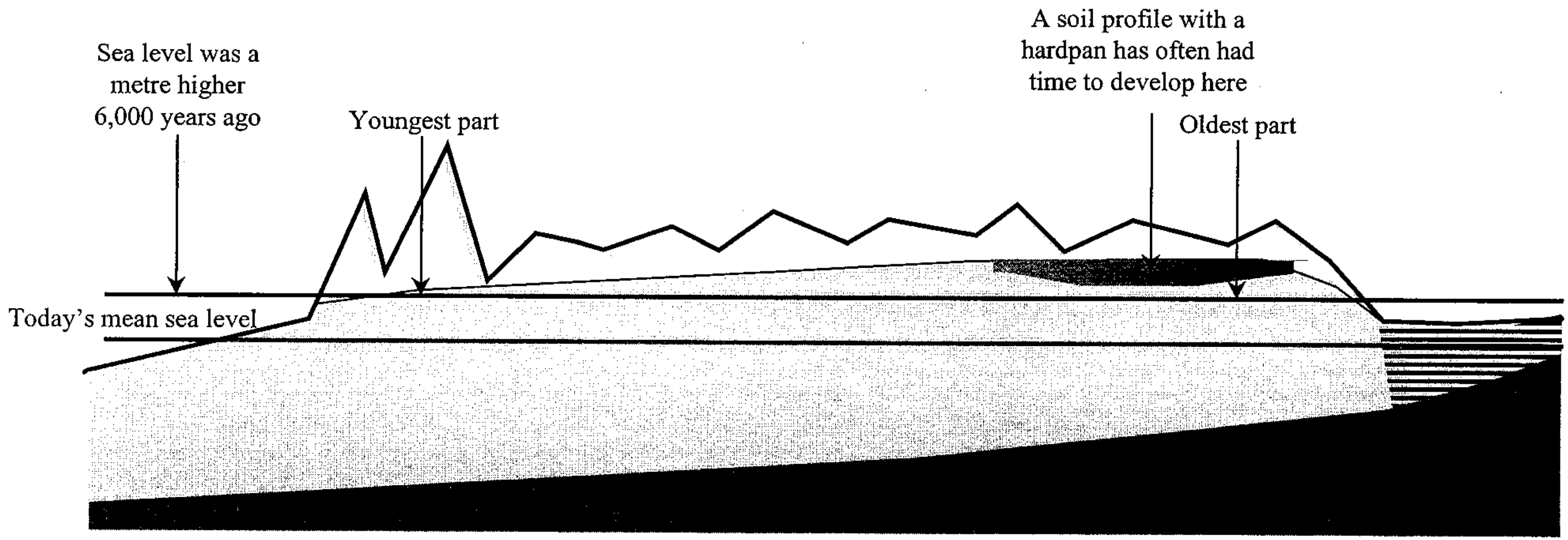
Many spits are at least 100 times wider from front to back than they are thick.



Spits grow seawards

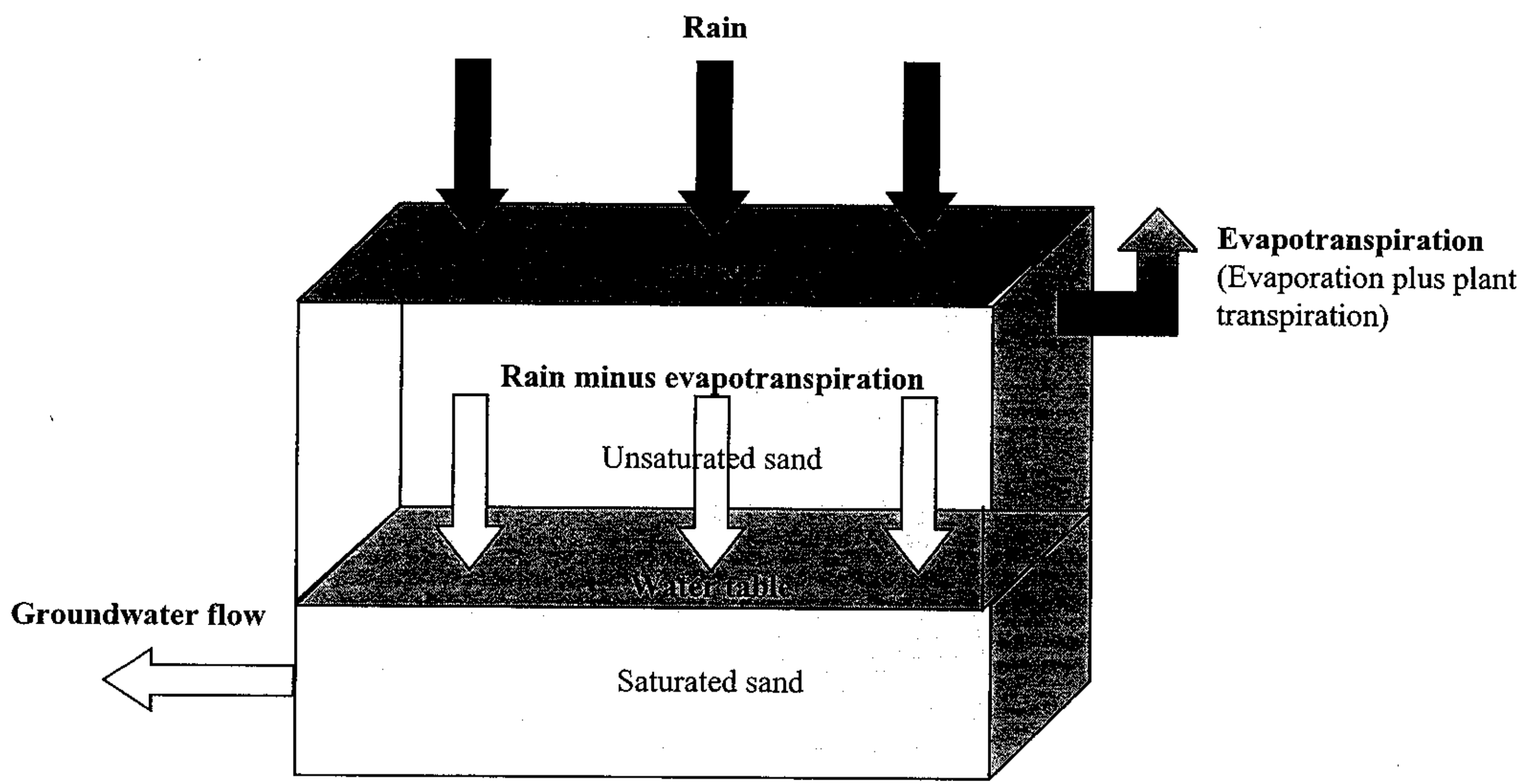
The oldest part of a spit is at the landward side.

Most spits are between about 5,000 and 10,000 years old.



Groundwater in a typical spit comes from rain

All spits contain relatively fresh groundwater. The groundwater is derived from infiltrating rain, part of which has already evapotranspired. The remainder moves vertically downwards, until it reaches the water table.
The water table is the upper surface of the layer of saturated sand.

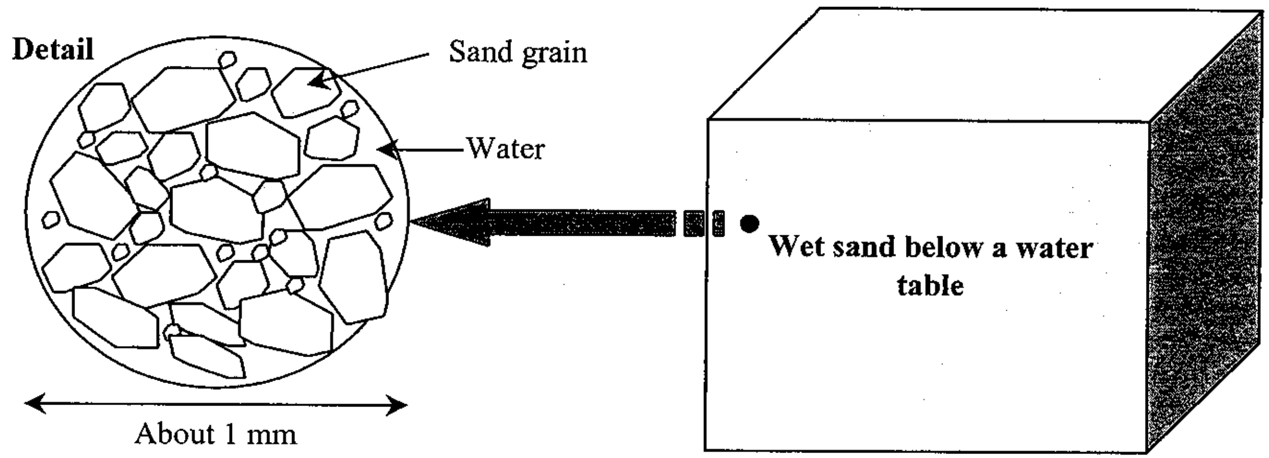


Coastal sands are unconsolidated, unconfined aquifers

Unconsolidated means loose, or not cemented. Water is stored, and moves, between grains of sand below a water table in a sand spit.

An aquifer is any subsurface material which contains groundwater and is capable of supplying it at useful rates to users. A saturated clay contains groundwater but is not an aquifer because water cannot be extracted from it at a useful rate.

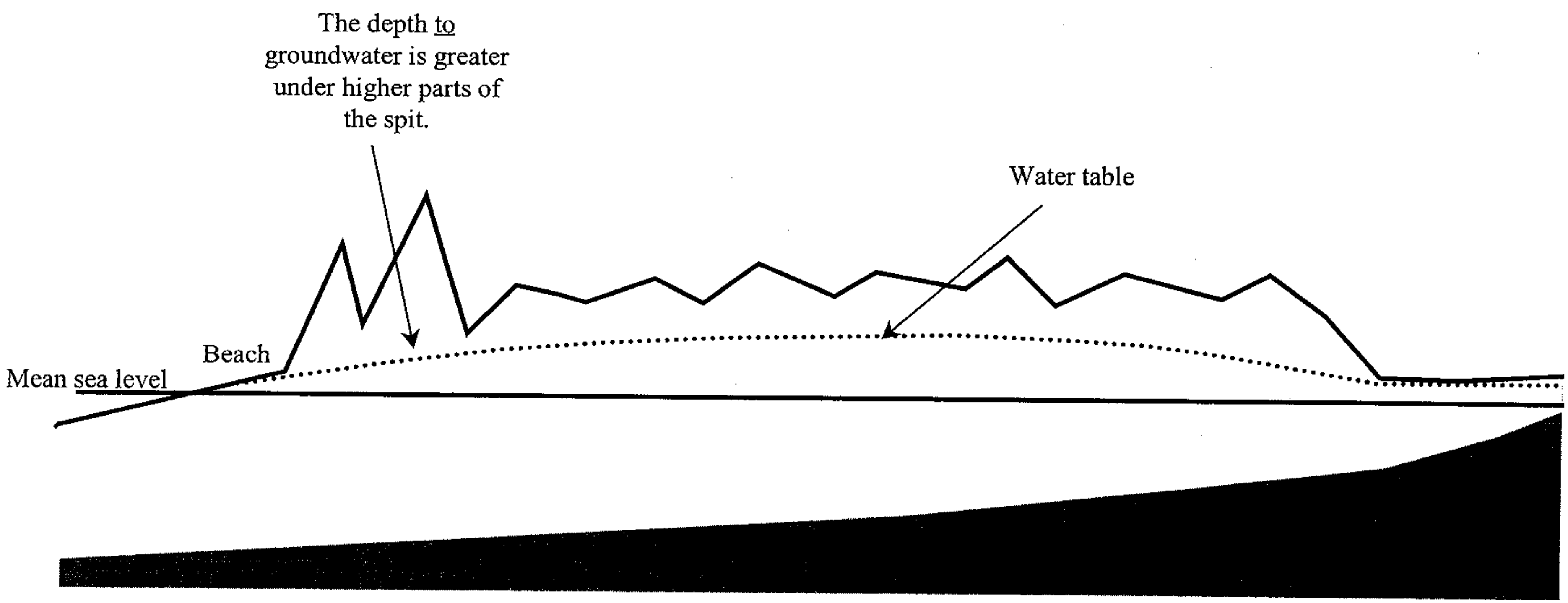
An unconfined aquifer contains a water table at which the water is at atmospheric pressure.



Water is stored between loose sand grains in an unconsolidated aquifer

The shape of the water table in a typical spit

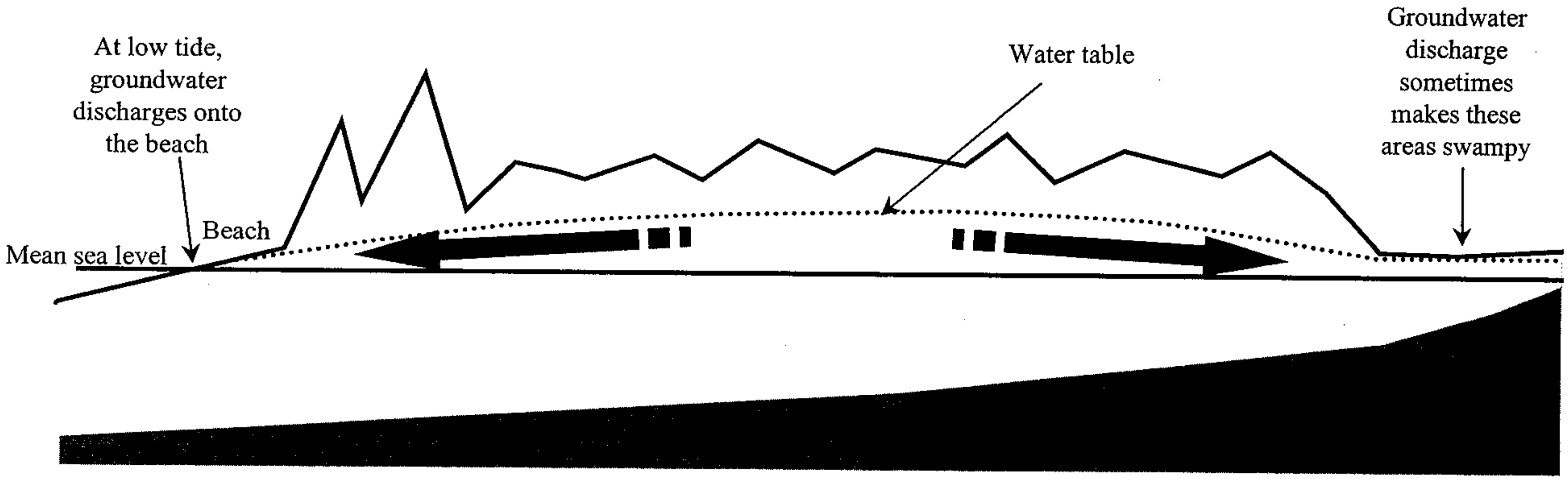
The water table in a spit is always higher than mean sea level, and is usually highest in the centre of the spit. It slopes seawards, and also often slopes to the rear of the spit.



Groundwater moves seawards (and often landwards)

Groundwater always moves in the direction that the water table slopes (ie downgradient)

In this example, it moves coastwards <u>and</u> landwards, as shown by the thick arrows.



Groundwater moves slowly in coastal sands

The rate that groundwater flows through a coastal sand aquifer depends directly on the permeability of the aquifer and the slope of the water table (ie the water table gradient), and inversely on the porosity of the aquifer. The equation for groundwater flow rate is:

$$\text{Flow rate (in metres per day)} = \frac{\text{permeability x water table gradient}}{\text{porosity}}$$

Typical permeabilities are between 5 and 10 metres per day. Typical gradients are 1 in a 100 (a metre fall in water table level in 100 horizontal metres), or 0.01. Typical porosities, as we have seen, are between 20% and 30% (ie between 0.2 and 0.3).

Example

A coastal sand aquifer has a permeability of 5 metresper day, a water table gradient of 0.01, and a porosity of 0.2. At what rate does the groundwater flow?

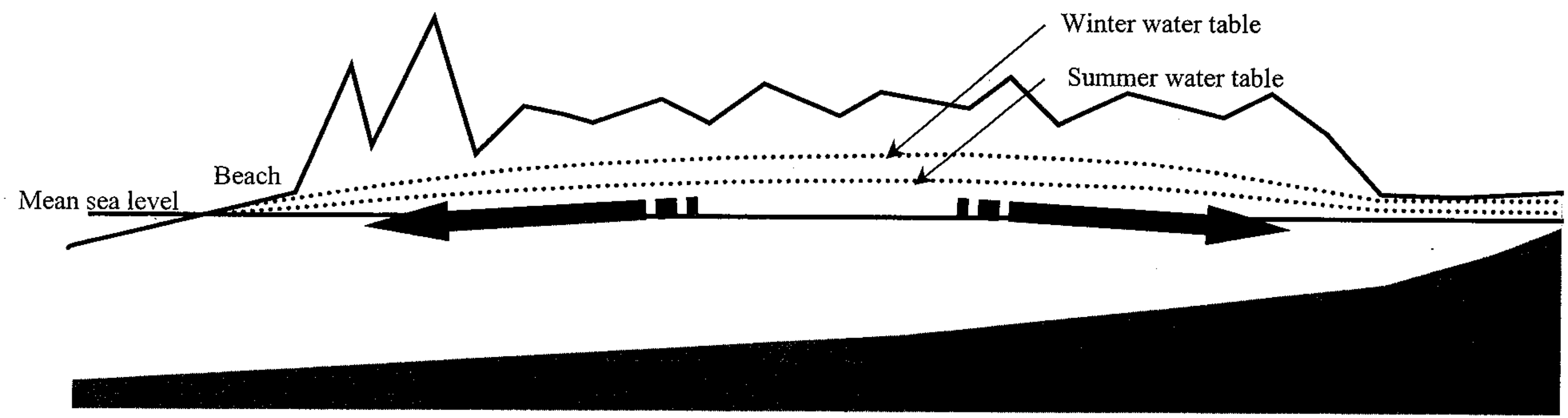
Answer

Use the equation above. Flow rate $= \frac{5 \times 0.01}{0.2} =$ 0.25 metres per day

This is a flow rate of 91 metres per year. If the gradient is halved, the flow rate halves.

The shape of the water table is always changing

The water table rises and falls in response to infiltrating rain. A seasonal variation of ametre or so is not unusual. If no rain fell, the water table would gradually flatten out, but at a decreasing rate.

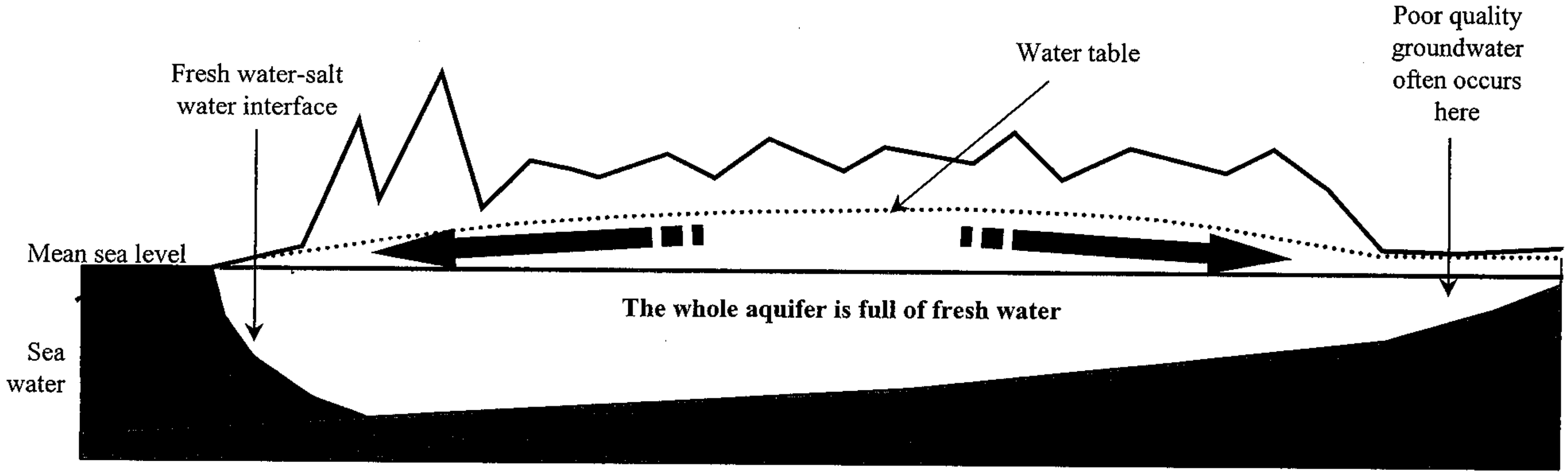


An aquifer with a shallow clay base is full of fresh water

In spits with a clay base at depths around 10metres, all of the sand below the water table contains fresh water, all of it derived from infiltrating rain.

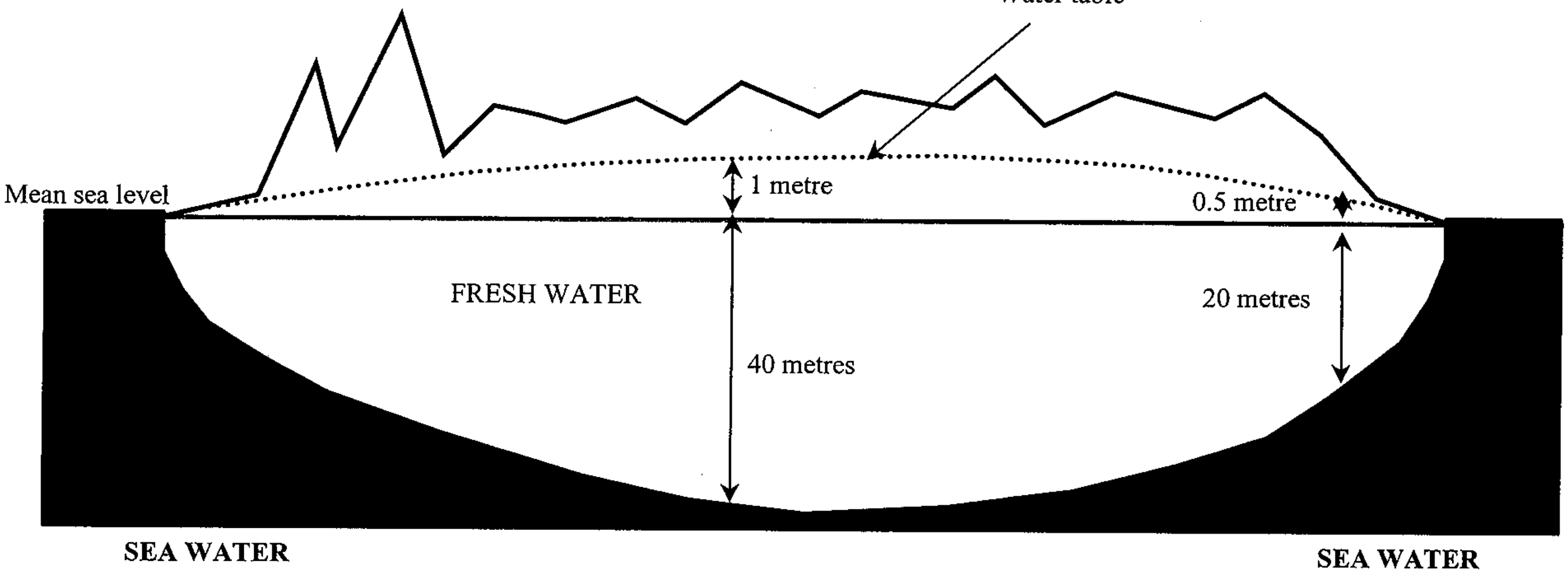
Fresh water therefore extends below sea level.

There is a narrow mixing zone beneath high water mark where fresh water and sea water blend. It is called the fresh water-salt water interface.



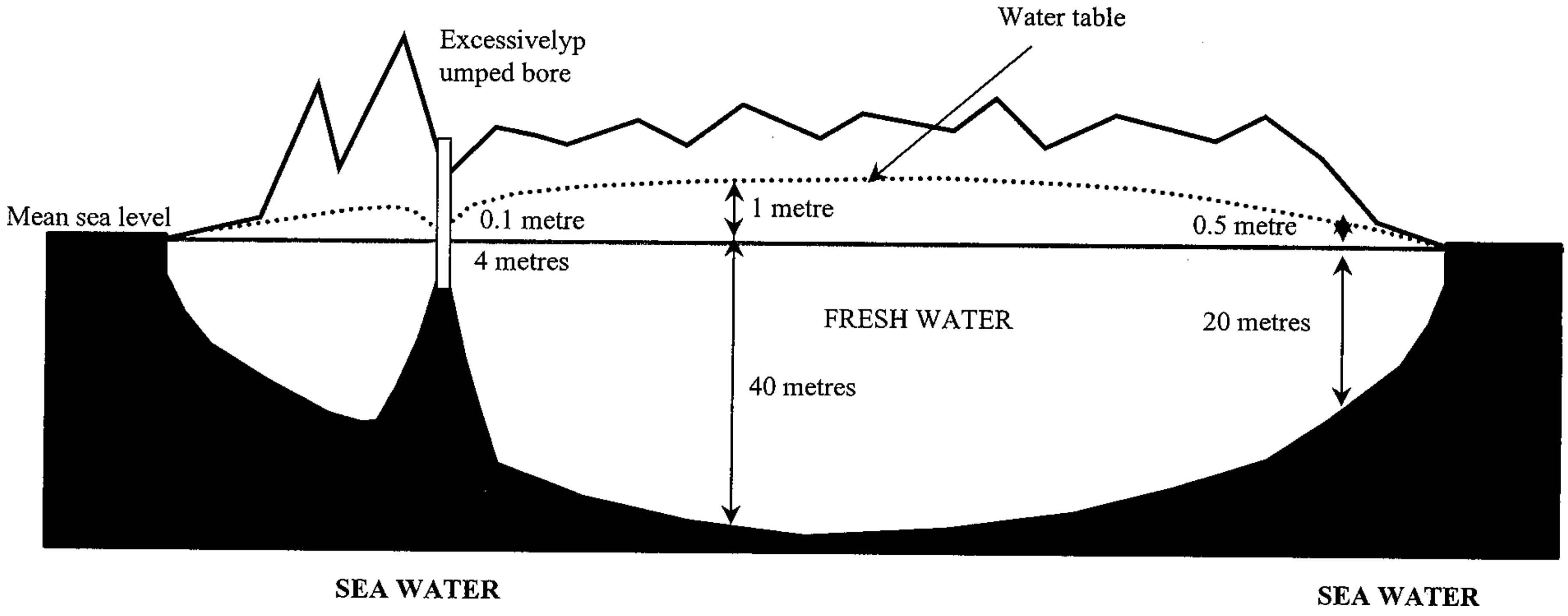
Sea water sometimes underlies fresher groundwater

<u>In spits with no clay base, or with very deep clay bases</u> fresh water sits on sea water. One metre of fresh water above sea level supports a 40 metre thick column of fresh water below sea level.
This is because fresh water is 1/40th less dense than sea water.



Sea water intrusion (1)

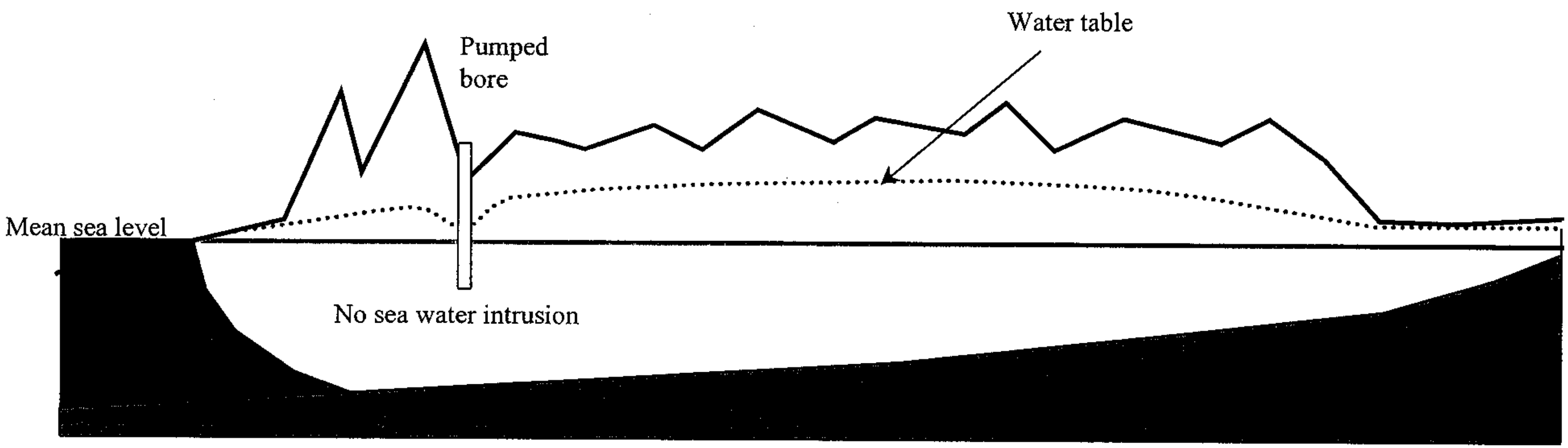
In spits with no clay base, or with very deep clay bases sea water intrusion can be caused if a bore is pumped at a rate which lowers the water table too much, especially near the coast. If in the example below the height of the water table above sea level is reduced to 0.1 metres, the depth of fresh water below sea level is reduced to 40 x 0.1 = 4metres. Sea water (or brackish water) enters the bore from below.



Sea water intrusion (2)

<u>In spits with a clay base at depths around 10metres</u>, it is more difficult to induce sea water intrusion. This is because all of the sand below the water table contains fresh water.

The bore in the example below is pumped at the same rate as the bore the previous slide, but the clay layer prevents the sea water from 'feeling' the effect. In other words, the water table between the bore and the coast has not been lowered enough for sea water intrusion to occur. To cause intrusion, this bore would need to be closer to the coast, or be pumped for longer periods, or be pumped at a higher rate, or any combination of these.



Sea water intrusion (3)

There have been no recorded instances of sea water intrusion in coastal sands in Tasmania, despite these aquifers having been used for decades on various scales for domestic, town, and golf club irrigation supplies.

Groundwater quality (1): Measuring salinity

Groundwater quality is often described by **salinity**, or **Total Dissolved Solids**(TDS), of the groundwater. Salinity is usually expressed as milligrams per litre (mg/L). For example, one gram of salt dissolved in 1,000 L of water produces a salinity of 1 mg/L (one part in a million).

Dissolved solids usually includecations like calcium, sodium, potassium and magnesium, and anionslike chloride, bicarbonate and sulphate.

Another way to describe salinity is by **Electrical conductivity** (EC) of the groundwater, measured in millisiemems per centimetre (mS/cm), or microsiemens per centimetre. (Mr Siemen was a Swedish scientist)

To approximately convert from EC (in mS/cm) to TDS, multiply EC by 650.

Example: a groundwater with an EC of 0.4 mS/cm has an approximate salinity of 0.4 x 650 = 260 mg/L.

Salinities less than about 1,000 mg/L are usually regarded aspotable, but salinities less than about 500 mg/L are more desirable. Groundwater should, however, be fully and regularly tested before human consumption.

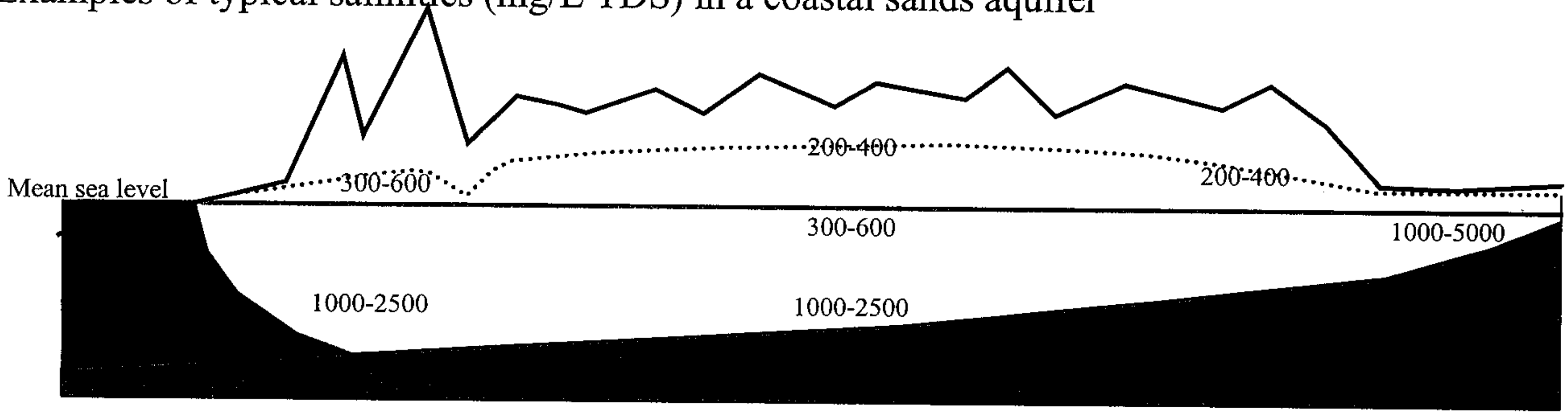
Sea water has a salinity of about 33,000 mg/L.

Groundwater quality (2): Usually good in coastal sands

Groundwater in coastal sands is usually of good quality because it is derived directly from infiltrating rain. Salinity usually increases with time because minerals are slowly dissolved from the grains of sand, shell, wood, charcoal etc which make up the coastal sand body.

Therefore, groundwater quality often changes horizontally and vertically in a coastal sands aquifer. The lowest-salinity water occurs at the water table. Deeper groundwater is often of higher salinity. So too is groundwater nearest to the beach, because it is subject to more salt spray blown off the seawater.

Examples of typical salinities (mg/L TDS) in a coastal sands aquifer



Groundwater quality (3): Iron precipitates and rotten egg gas

Groundwater in coastal sands almost always contains dissolved iron, and hydrogen sulphide gas (rotten egg gas, or H_2S).

Iron

The dissolved iron - often no more than about one mg/L - is readily precipitated as orange red iron oxide (rust) when exposed to oxygen. This usually occurs around the slots in a spear bore, or in water tanks, on grass or houses when irrigated, or in washing machines and clothes.

Precipitated iron (also with black manganese dioxide) often blocks spear screens, and is the main reason why pumping rates decrease slowly with time. The problem is easily remedied.

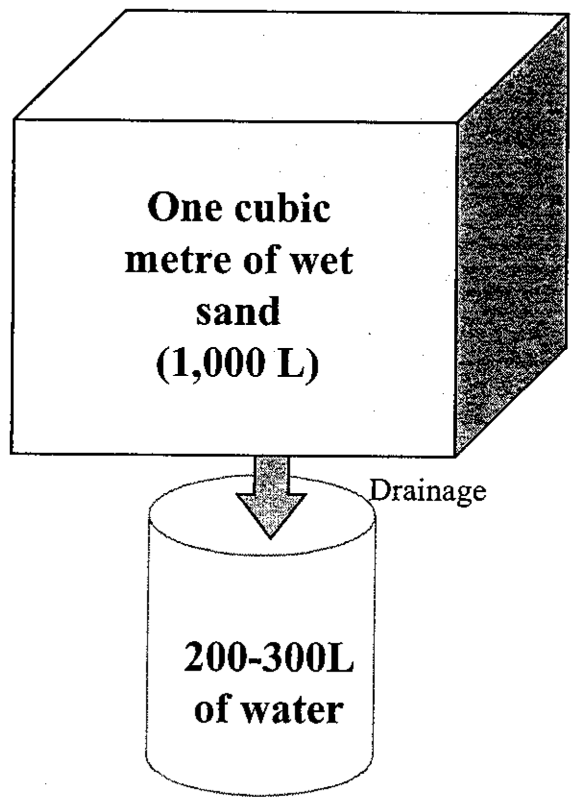
Rotten egg gas

The H_2S gas is produced by natural processes in the deeper levels of the aquifer - below the level at which the water table fluctuates. Sulphate (SO_4), originally from sea water, is reduced in the absence of oxygen and combines with hydrogen in water. H_2S is a poisonous gas, but fortunately it is very smelly and easily detectable at levels less than 1 mg/L - concentrations too low to be of harm. It is also very volatile, so it is lost quickly from groundwater pumped to the surface.

Groundwater reserves (1): Sands can hold a lot of water

Loose, unconsolidated sands have a porosity of between about 20% and 30%. This means that, by volume, they are about 20% to 30% open space. This open space is filled with water below the water table.

A cubic metre (ie 1,000 Litres) of wet sand therefore contains between about 200 and 300Litres of water.



Groundwater reserves (2): How much in a loose sand aquifer?

The amount of groundwater stored in a coastal sands aquifer is easily calculated as

Reserves	=	volume of saturated sand x porosity
or		
Reserves	=	length x width x saturated depth x porosity

Example: **Dolphin Sands (Nine Mile Beach) at Swansea** (say, 14 km long, 1 km wide, 7 m of saturated sand)

Reserves	=	14 km x 1 km x 7 m x (say) 25%
	=	14,000 m x 1,000 m x 7 m x 0.25
	=	24,500,000 cubic metres
	=	24,500,000 kilolitres
	=	24,500 megalitres
	=	24,500,000,000 Litres (24.5 billion litres)
	=	enough to provide each person on earth with 4litres

It would be practically impossible to remove all this water from the aquifer. It would require a grid of bores, at say 20 metre centres, to completely cover the aquifer. At least 30,000 bores would be needed. If each were pumped at 1,000 L/hour, it would take a month to completely remove the fresh water resource - provided it didn't rain.

Groundwater reserves (3). What is sustainability of use?

Sustainability of groundwater use in any aquifer means not extracting more water than is, on average, replaced by natural processes ie

groundwater use = recharge

In a coastal sands aquifer, this means limiting groundwater use to that equal to the amount of infiltrating rain falling directly on the aquifer, minus evapotranspiration. The period of time over which we calculate the recharge should be long enough to 'iron out' short-term fluctuations in recharge. A year is often used. Therefore, on a long-term basis, for sustainability of supply,

annual groundwater use = annual recharge

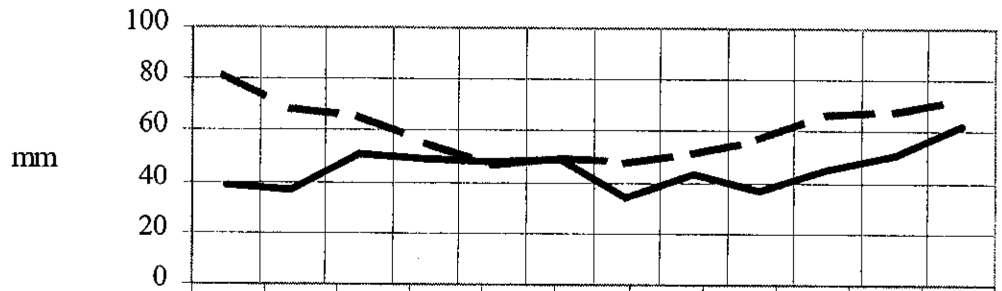
or

annual groundwater use = mean annual rain - evapotranspiration

Groundwater reserves (4): Estimating annual recharge

Example: Dolphin Sands (Nine Mile Beach) Monthly rainfall from 4 nearby stations available.

This graph, using **lowest** monthly rainfall figures, shows that essentially no rain recharges the aquifer in years of below-average rainfall (the dashed evapotranspiration curve is always above the black rainfall curve).



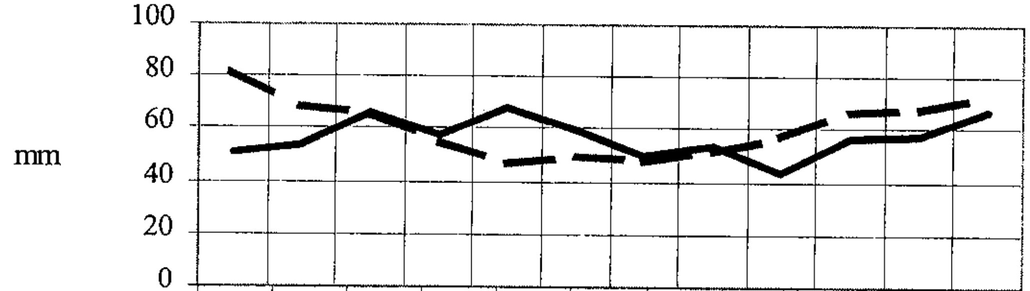
	Jan	Feb	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec
Rainfall	39	37	51	49	48	49	43	37	45	51	62
Evapotranspiration	82	69	66	56	47	50	52	58	67	68	74

Groundwater reserves (5): Estimating annual recharge

Example: Dolphin Sands (Nine Mile Beach) Monthly rainfall from 4 nearby stations are available.

This graph, using **highest** monthly rainfall figures, shows that rain recharges the aquifer in five months of the year (but mainly May and June) during years of high rainfall (the dashed evapotranspiration curve is below the black rainfall curve for March-July). The annual rainfall excess over evapotranspiration is about 40 mm in this example.

DOLPHIN SANDS
Mean monthly rainfall vs estimated monthly evapotranspiration
(highest monthly rain from 4 stations)



	Jan	Feb	Mar	Apr	May	Jun	Aug	Sep	Oct	Nov	Dec
Rainfall	51	54	66	58	68	59	54	43	57	58	67
Evapotranspiration	82	69	66	56	47	50	52	58	67	68	74

Rainfall — Evapotranspiration

Groundwater reserves (6): Estimating annual recharge

Example: Dolphin Sands (Nine Mile Beach)

The previous two examples from Dolphin Sands demonstrate that, to be sustainable, groundwater use is directly related to annual rainfall (since annual evapotranspiration is approximately constant).

In the last example, a net excess of about 40 mm of rain reached the water table and recharged the aquifer.
This 40 mm of recharge was added to every square metre of the aquifer. Since one millimetre of water over one square metre equals one litre, the recharge over the year amounted to 40 litres per square metre. On a one hectare lot (ie 10,000 square metres) the recharge was 400,000 litres.

Based on this example, the owner of a one hectare lot would, for sustainable groundwater use, be environmentally responsible if he or she limited annual groundwater extraction to around 400,000 litres, or about 1,100 litres a day.
More groundwater would be available in wetter years, and less in drier years. Short term pumping in excess of the daily allowance would of course also be appropriate.

Extracting groundwater (1). Spear bores and wells

Groundwater is easily extracted from coastal sands because

it is at a shallow depth,
bores (spears) are low-cost and readily installed,
pumping costs are low, and
the relatively high permeability of the sands allows useful amounts of groundwater to be pumped

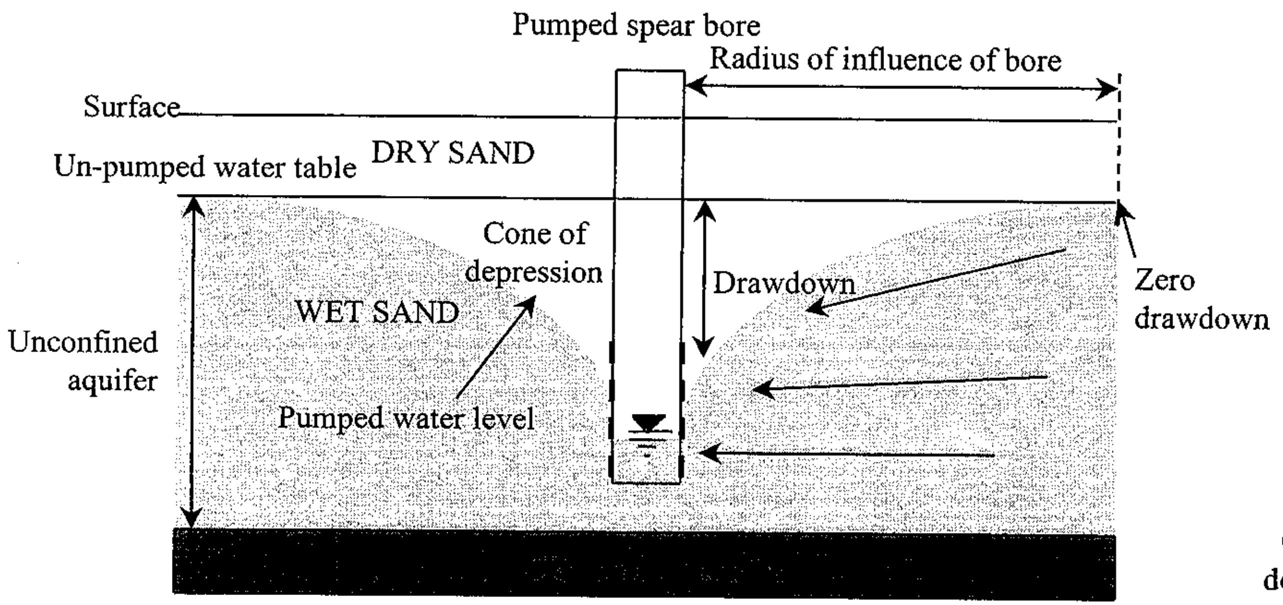
Spear bores and wells are most commonly used.

A spear installed to between about 2 and 4 metresbelow the water table should continuously yield between about 750 and 1,500 litres per hour without pumping air. The key factor is depth below the water table.

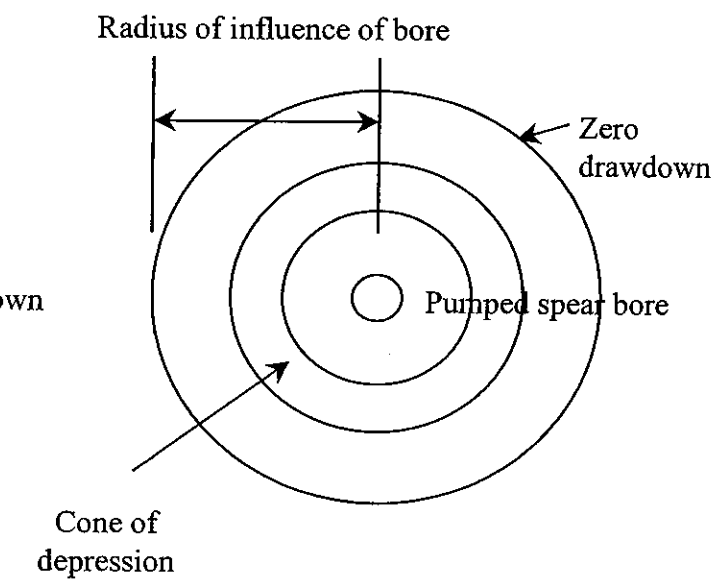
Extracting groundwater (2): Effects of pumping

Pumping from a spear bore or well drains the sand around the spear, lowering ('drawing down') the water table into a cone of depression.

In section



In plan

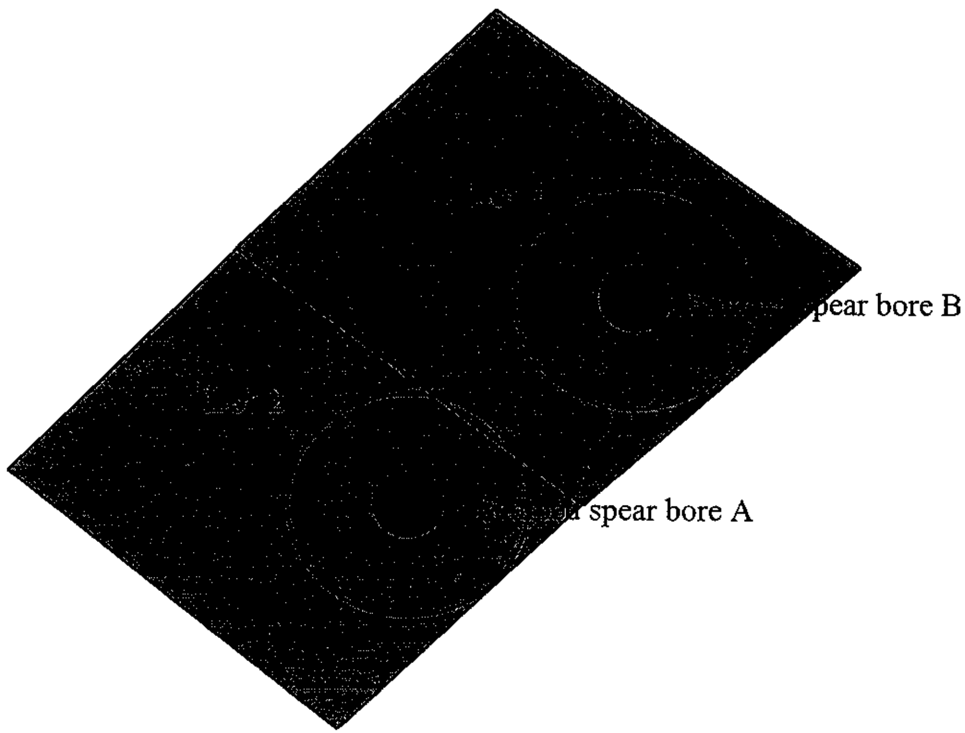


Extracting groundwater (3). What about my neighbour's bore?

It is true that if neighbouring spears are too close, their cones of depression overlap, drawdowns are additive, and each spear is taking the other's water.

However, the radius of influence of a typical spear in a coastal sand aquifer would seldom exceed about 15 to 20 metres. If neighbouring spears are more than about twice this distance apart, interference is unlikely.

In this example, spear bores A and B do not interfere because their radii of influence (the two circles) do not overlap.



Groundwater contamination (1): General sources

Groundwater contamination is possible from:

Domestic wastewater disposal
Stormwater runoff from roofs
Garden fertilisers, pesticides, herbicides and manures
Stormwater runoff from bitumen roads
Spilt hydrocarbons including petrol, diesel, paints, greases, oils, thinners

Examples of such contamination arising from domestic activities are not common in coastal sands. For example, the township of Lauderdale, on a spit with a water table at twometres, has about 400, closely-spaced septic tank systems with absorption trenches, and roof and bitumen road runoff to soakage pits. No significant contamination - including bacteria or pesticides - was detected. Elevated nutrients (nitrates and phosphates) were found in groundwater near the trenches, but concentrations decreased dowgradient as the nutrients naturally attenuated in the groundwater.

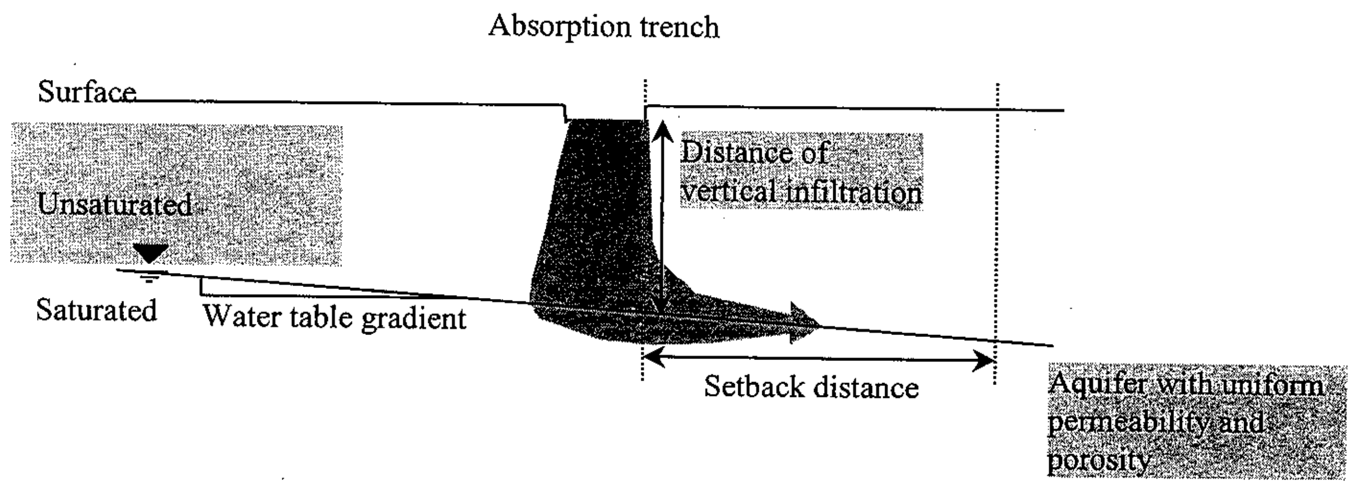
Groundwater contamination (2): Bacteria and viruses

It is advisable not to extract groundwater for human consumption if there is a high risk of its contamination from wastewater disposal. Spears should therefore not be sited too close to such facilities.

Coastal sands are good filters of bacteria. Usually, bacteria are undetectable in groundwater beneath an absorption trench.

Viruses usually survive for longer times. They travel with the groundwater, and die of at a rate determined by the groundwater temperature. After a certain time, they too have all died off. This is the **viral-die off time**, which depends on the number of viruses originally present (ie the quality of the effluent).

The distance over which this happens depends on how quickly the groundwater is moving (which in turn depends, as we have seen, on water table gradient, and aquifer permeability and porosity). This distance is called the setback distance.



Groundwater contamination (3). Setbacks in coastal sands

The following are approximate viral setback distances for a typical coastal sand aquifer, **assuming** a permeability of 10 m/day, a porosity of 0.25 (ie 25%, a water table gradient of 1 in 200 (ie 0.005) and a groundwater temperature of 12 degrees C. The setbacks will vary for every site and aquifer.

	Approx. min. setback distance for viral die-off
For septic tank effluent	about 20 m, but say 25 m
For greywater	about 12 m, but say 20 m
For discharge from AWTS's	about 10 m, but say 15 m

Groundwater contamination (4): Separation distances

Question

How close to my absorption trench (or my neighbour'strench) can I install a spear bore?

Answer

The further the better. But use the following as a guide.

If the absorption trench is **up-gradient** of the spear bore, the minimum separation distance is

Separation distance = trench setback distance + spear bore radius of influence

If the absorption trench is **down- or cross-gradient** of the spear bore, the minimum separation distance is

Separation distance = spear bore radius of influence

These relationships are shown in the next slide.

Example form Nine Mile Beach

Setback distance for septic tank effluent = 25 metres

Spear bore radius of influence = 20 metres

Separation distance = 45 metres if the trench is upgradient of the bore

Separation distance = 20 metres if the trench is cross- or downgradient of the bore

Groundwater contamination (5): Separation distances

Example from Nine Mile Beach (approximate only)

Trench setback distance for septic tank effluent = 25 metres

Spear bore radius of influence = 20 metres

Separation distance = 45 metres if the trench is upgradient of the bore

Separation distance = 20 metres if the trench is cross- or downgradient of the bore