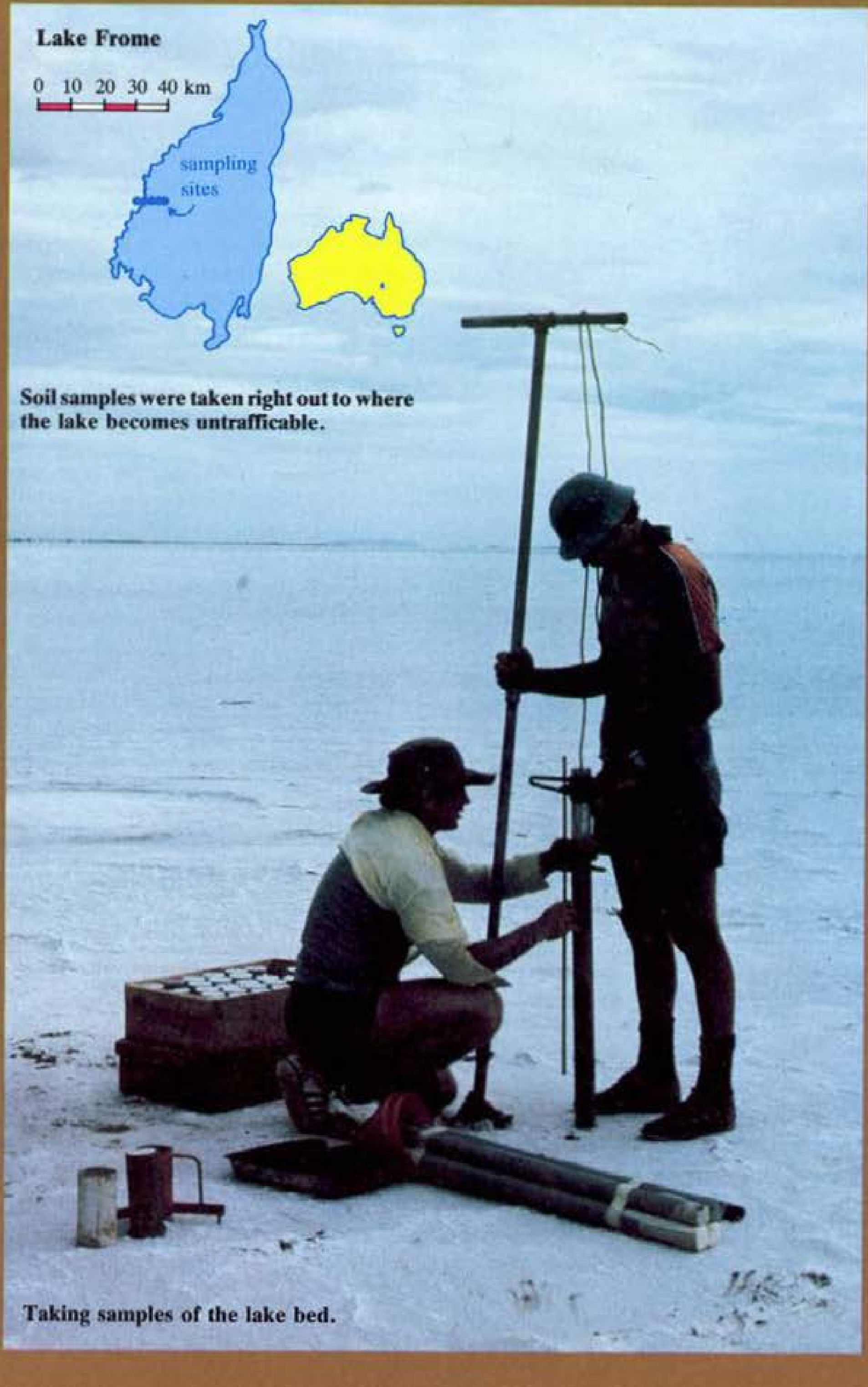
Evaporation from a 'dry' salt lake

For years on end you'll never see water in Lake Frome — a huge dry salt lake in the arid north of South Australia. But measurements made by scientists from the CSIRO Division of Soils indicate that 500 million cu. m of groundwater evaporates annually through the lake's salt-encrusted surface.



Soil samples were taken right out to where the lake becomes untrafficable.

Taking samples of the lake bed.

Lake Frome, covering 2700 sq. km, is a good example of the many dry salt lakes that occur throughout Australia's arid interior. The annual rainfall in the area is typically only 140 mm, and the lake last contained surface water of significance in 1973/74. As always, the water soon evaporated, leaving behind a salt crust. It is very difficult for any water to persist in an environment where the evaporation rate from a free water surface has been measured at 3 metres a year.

Nevertheless, beneath the crust, the soil remains moist, as it is in contact with groundwater. In most parts of the lake the water table is very close to the surface.

Since the crust is porous, water constantly evaporates through it, and the scientists, Dr Graham Allison and Dr Chris Barnes, were curious to find out how much groundwater is lost this way.

Where has all the salt disappeared to?

They devised a method of measuring the evaporation rate through a porous surface based on measurements of two stable isotopes that occur naturally in water.

The isotopes are deuterium (heavy hydrogen), which occurs in rain-water at 1 part in 6400, and oxygen-18, at one part in every 500.

If no evaporation takes place from the lake then the isotopes remain uniformly mixed throughout the subsoil moisture.

However, the surface faces harsh desert conditions that have a powerful drying effect, and any soil moisture is drawn to it. Water vapour diffuses upwards and is lost to the desert air. This is replaced by more water vapour. At some depth, an interface between water as vapour and water as liquid is encountered. Water evaporating at this interface is replaced by liquid moving up by capillary action.

So, by diffusion and capillary action, the drying sun draws on the groundwater supply. Significantly, when water is in vapour form, the isotopes mentioned move at slower rates than their more abundant, and lighter, siblings.

As a result, a degree of concentration of these isotopes takes place. The scientists calculated that the profile with depth of an isotope's concentration should vary in a systematic way with the evaporation rate from the surface. The profile also depends on the water content of the soil, which can be readily measured.

Lake Frome: vast stretches of flat, salt-encrusted surface.

When Dr Allison and Dr Barnes took sample cores from six sites on the surface of Lake Frome, the isotope profiles generally showed the expected regularity. The isotope concentrations, measured with a mass spectrometer, showed an enhancement in oxygen-18 concentration of up to 1·6%; deuterium differed from the norm by up to 3%.

A depth profile of deuterium concentration at one particular site is shown on the next page. This profile shows a peak deuterium concentration at a depth of 25 mm. According to the theory of soil physics that the two researchers applied to the situation, the depth at which the peak occurs can be related to the evaporation rate, in this case about 50 mm per year.

The rate at which the excess isotope concentration dwindles as depth increases should also depend on evaporation rate, theory says. This alternative way of calculating the evaporation rate leads to a figure of 90 mm per year. The co-workers place much more reliance on this second method, as it is based on a greater number of observations. Also, it is not susceptible to errors in gauging the porosity of the soil and of the salt crust — a necessary part of making the first calculation.

A third method, using measurements of the concentration of chloride ions, which become concentrated in a similar way to the isotopes, was also assessed. It yielded results generally similar to those given by the other methods.

An evaporating saucer

The sampling sites (shown on the map) stretched along a line beginning at the lake edge and ending more than 6 km out, where the lake becomes untrafficable. When the methods were applied to samples from each site, a consistent picture emerged. Evaporation was least near the edge (about 90 mm per year), and increased steadily towards the middle, reaching about 230 mm per year at the site furthest out.

This trend tallies with the saucer-like topography of the lake. Where the surface lies very close to the groundwater level, at the middle of the saucer, evaporation is greatest. This occurs at, and beyond, the last sampling point, where the surface is effectively saturated. The central 25 km of the lake is level to within 0·5 m, and the evaporation rate over it should be close to the maximum figure inferred from the measurements at the fifth site.

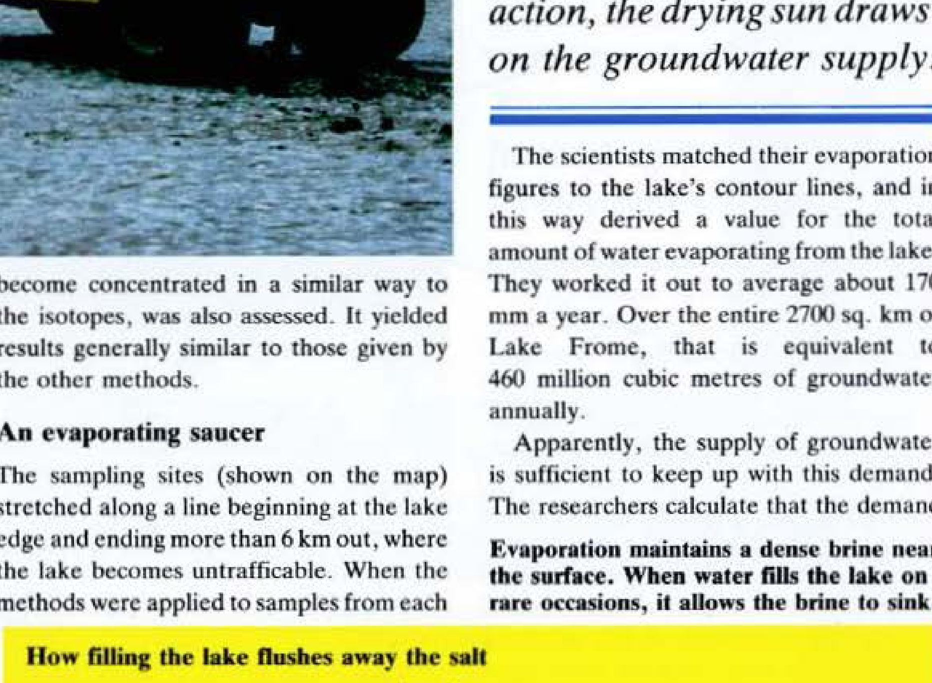
By diffusion and capillary action, the drying sun draws on the groundwater supply.

The scientists matched their evaporation figures to the lake's contour lines, and in this way derived a value for the total amount of water evaporating from the lake. They worked it out to average about 170 mm a year. Over the entire 2700 sq. km of Lake Frome, that is equivalent to 460 million cubic metres of groundwater annually.

Apparently, the supply of groundwater is sufficient to keep up with this demand. The researchers calculate that the demand

Evaporation maintains a dense brine near the surface. When water fills the lake on rare occasions, it allows the brine to sink.

How filling the lake flushes away the salt



can be met by only 1 mm of rain a year over the entire Lake Frome catchment finding its way into the groundwater.

Disappearing salt

One interesting problem raised by this result concerns the salt budget of the lake. The inflowing groundwater carries a salt burden of some 5 kg per cu. m. If this salinity level has persisted over the last 10 000 years, then each square metre of Lake Frome should have accumulated 10 tonnes of salt!

Lake Frome's salt crust is nowhere near the 5-m thickness this implies. A crust only about 200 mm thick covers about 6% of the lake surface, and in most places it is barely 5 mm thick. Where has all the salt disappeared to?

If it's not appearing on the surface, then some subsurface mechanism must be transporting it away. One suggestion has been made for another unexpectedly salt-free salt lake (Lake Tyrell, in western Victoria). Perhaps when the groundwater becomes too salty, the water's density is enough for it to sink down against the general upward flow induced by surface evaporation.

The scientists' measurements have given them another clue and, taking cognizance of it, they have proposed the following model for Lake Frome.

They found that the isotope concentration of the groundwater (water at 1 m below the surface, well away from the isotope-imbalancing evaporation process at the surface) differed systematically from the lake edge to the middle. This is hard to explain if a uniform body of groundwater is welling up towards the surface.

The scientists believe the isotope difference is a vestige of the lake's last filling 12 years ago. As this water progressively evaporated, its isotope levels were enhanced. And so the most enriched water was that at the centre, the last to evaporate.

That these isotopes are still to be found deep beneath the lake bed is a sign that the water that once filled the lake seeped downwards into the soil.

The isotope profile should vary in a systematic way with the evaporation rate.

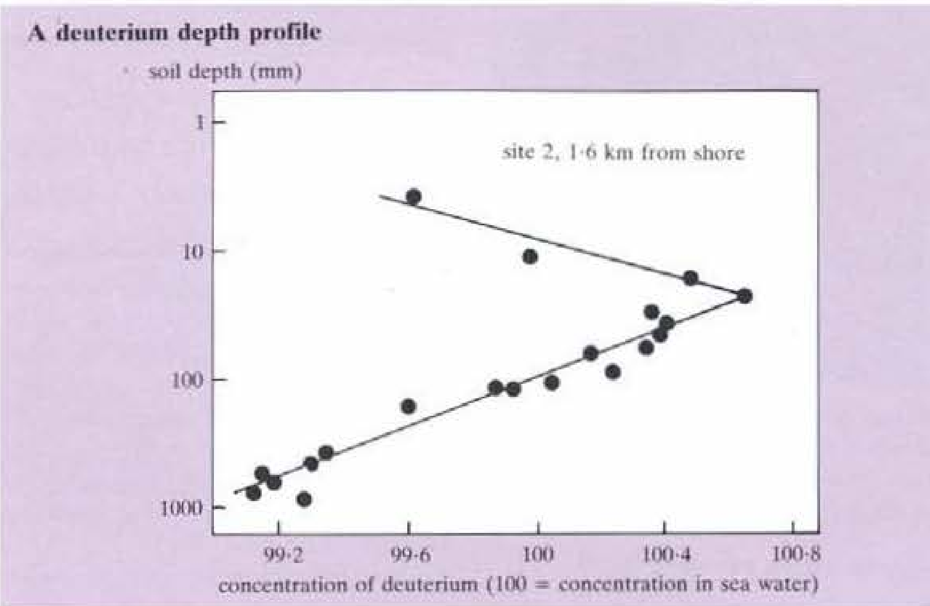
And why should it do this? Because the dense brine, now temporarily relieved of the evaporative forces sucking it to the surface, had a chance to sink. In other words, when water fills the lake, it gets the rare opportunity to flush away the salt accumulated since the lake was last refreshed.

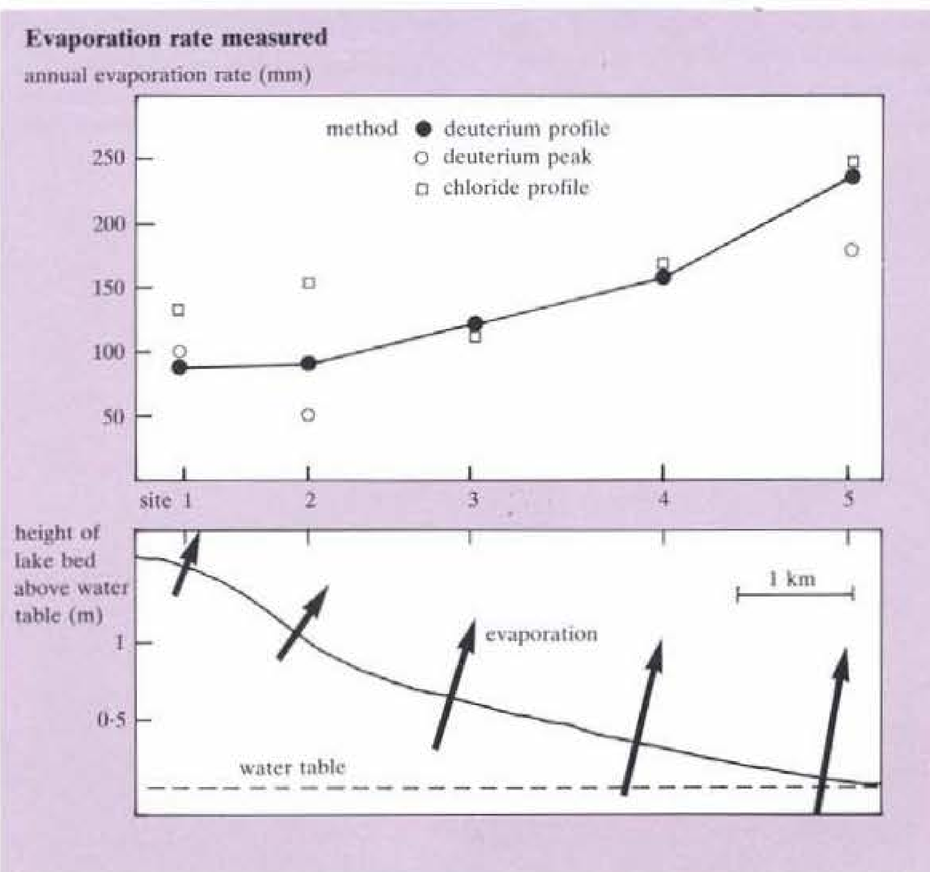
The isotope method of measuring evaporation can be applied to any area that is dry for years at a time. Recently, Dr Allison and some French colleagues used it to measure the evaporation from a deep water table in the Sahara.

Dr Barnes, now at the Division of Water and Land Resources, is using the method to help the Bureau of Mineral Resources measure groundwater losses from the Amadeus Basin, an artesian basin in the region of Ayers Rock.

Andrew Bell

The scientists used a mass spectrometer to measure the deuterium content of Lake Frome's bed at each site. The shape of the profile depends on the evaporation rate.





Three methods were used to measure evaporation. All showed that evaporation increased towards the lake's centre.

More about the topic

Estimation of evaporation from the normally 'dry' Lake Frome in South Australia. G.B. Allison and C.J. Barnes. *Journal of Hydrology*, 1985, **78**, 229–42.