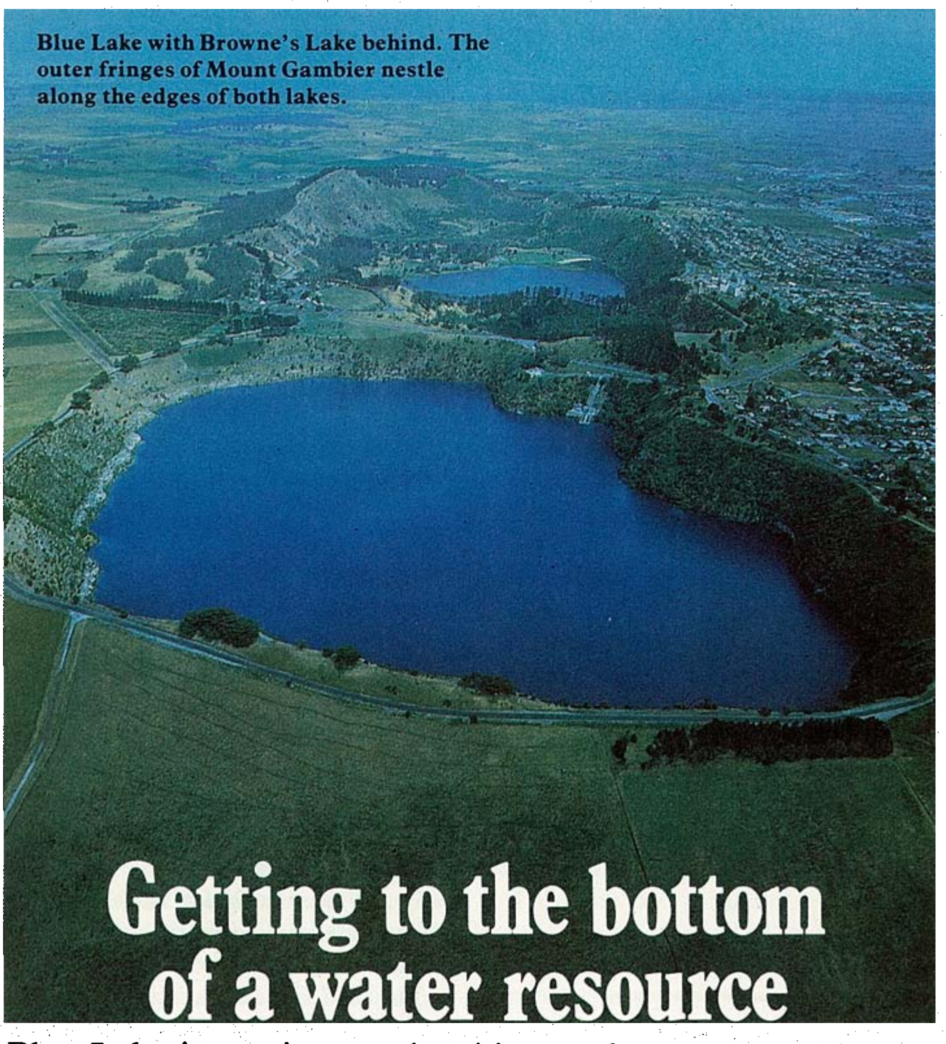


Blue Lake with Browne's Lake behind. The outer fringes of Mount Gambier nestle along the edges of both lakes.

Getting to the bottom of a water resource

Blue Lake is precious to the citizens of Mount Gambier, in the south-eastern corner of South Australia. Not only is this strikingly coloured natural feature a considerable tourist attraction, it also supplies the city's water.

But a number of developments may threaten it. For one thing, pumping out too much water for urban use could lower the lake's level, and thus reduce its amenity value. For another, nitrate pollution of nearby groundwater has been causing concern. Could this pollution seep into the lake?

Then too there is scope for greatly increasing irrigation in the region using the extensive groundwater resource that lies beneath the 6000-sq-km limestone plain on which Mount Gambier stands. Drawing on this groundwater may also affect the lake.

Over the years, Blue Lake's level has varied by about 8 metres, and these changes can be related to local land use. The lake reached its lowest known level in 1841. At that time the limestone plain would have supported its original cover of open eucalypt woodland. By 1910, Blue Lake's waters had risen 8 m and had reached their highest recorded level. By then nearly all the woodland had been cleared to make way for grassland pastures. Today the lake's level has dropped once more close to that of 1841.

Nowadays, the pine plantations that supply wood to the Mount Gambier milling complex cover about one-tenth of the limestone plain, which is often known as the Gambier plain.

Some years ago, a team of scientists from the CSIRO Division of Soils showed that very little recharge to the groundwater occurs beneath the pine plantations on the plain. This finding had important implications, since the recharge depends entirely on rainwater sinking through the Gambier plain's very permeable surface into aquifers beneath. Thus, increasing the area of pine plantations will reduce groundwater recharge.

Blue Lake could suffer from two problems — a lower water level, and nitrate pollution.

Blue Lake drops

In its pristine state, the plain was unusual in that it had no drainage lines. All rainfall sank directly through its porous surface. However, local flooding occurred after heavy rain. Consequently, drainage ditches have now been cut to drain off the floodwaters.

So both planting pines and putting in these drainage ditches have reduced recharge to the aquifers beneath the Gambier plain. The drop in the waters of Blue Lake to the modern level almost certainly reflects that reduction.

Obviously, local authorities wish to understand how different types of land use will affect the aquifers before making decisions that may greatly change them. Recent research has gone a long way towards sorting this out.

Rain falling on the Gambier plain sinks down until it reaches a waterproof layer of clay. Here it forms a 'pool' of water in the porous limestone above, and this 'pool' is known as the Gambier limestone aquifer.

Beneath the clay layer lies another permeable one of sand and gravel, which itself lies above impermeable rock. This layer of sand and gravel forms a second aquifer — known as the Knight sands aquifer — beneath the first.

The CSIRO studies showed that the top aquifer drains into the lower one at a point some 30 km north of Mount Gambier, in Penola forest near Nangwarry. The scientists now believe that all water reaching the lower Knight sands aquifer comes from the Gambier limestone one above it.

Any water used for irrigation would come from the easily reached Gambier limestone aquifer. So for understanding the size of the water resource for irrigation, this is the one that matters.

How much water?

South of Penola forest, this aquifer drains towards the coast. Some of its waters finally come to the surface in coastal swamps and lakes like Piccanini Blue Lake and Ewen Ponds, but much drains out directly through the sea floor. In addition, some water drains into the Glenelg River, whose flow therefore increases considerably towards its mouth.

This drainage from the Gambier limestone aquifer represents the amount of water that could be safely used without running down the resource. The problem

Surface water lies on the Gambier plain after the winter rains. Much of this will sink in and recharge the aquifers below.

is how to accurately calculate its volume.

One way to do so is to calculate the average recharge each year to the aquifers. This recharge must, of course, balance the discharge. Traditionally, measuring water movements has involved using lysimeters. Water collected in these large tanks sunk in the ground is taken as representing the amount of recharge occurring. Installing these devices in large numbers costs a great deal. Also, observations must continue for enough years for the mean annual recharge to be revealed.

Dr Graham Allison, one of the original team from the Division of Soils, has therefore tried using quicker and cheaper methods. In particular he has developed techniques for using tritium — a radioactive form of hydrogen — in the environment.

Natural tritium occurs in the environment only in very small amounts. Cosmic rays cause it to form when they react with nitrogen atoms in the stratosphere. Like hydrogen, it occurs mainly as water. It reaches the ground in rain.

Nuclear fall-out used

In 1954, the Americans exploded their first H-bomb, which released, among other things, large amounts of the radioactive tritium into the atmosphere. Further nuclear tests in the atmosphere by the Americans, Russians, and British released more, with the result that atmospheric tritium concentration rose considerably.

Tritium has a half life of 12·26 years, and so once those three countries ceased testing in the atmosphere in 1963 its concentration began to fall back to the natural level. (The later French and Chinese tests did not greatly increase atmospheric tritium levels.)

All except the French tests were carried out in the Northern Hemisphere, where a very pronounced peak of tritium levels in rainwater occurred between 1962 and 1966. These northern nuclear tests also affected atmospheric tritium levels south of the equator, but here the peak of tritium concentration that occurred between 1963 and 1965 was nothing like as great.

Several Northern Hemisphere scientists have used tritium levels in groundwater to find out when that water actually fell as rain. Once tritium's spontaneous decay has been taken into account, water that fell as rain between 1962 and 1966 contains more tritium than any other. So this peak can be used as a fixed point for 'ageing' the water.

Dr Allison has taken the technique and adapted it to the more difficult conditions of the Southern Hemisphere, with its much lower tritium concentrations and lack of a pronounced peak.

He used it first to estimate recharge beneath pine plantations in Penola forest and under adjacent grasslands. He came up with the result that little recharge occurred beneath the pine forests (see *Ecos* 6), which confirmed earlier calculations

Drawing on this groundwater may also affect the lake.

carried out by two other members of the original CSIRO team — Mr John Colville and Mr John Holes (who is now Professor of Earth Sciences at Flinders University). These two scientists made their calculations from observations of the rise and fall of the water levels in shallow bore holes.

Since then, with the assistance of Mr Murray Hughes, Dr Allison has been able to use a similar technique to estimate the total recharge around Mount Gambier in an area that covers about one-quarter of the whole plain.

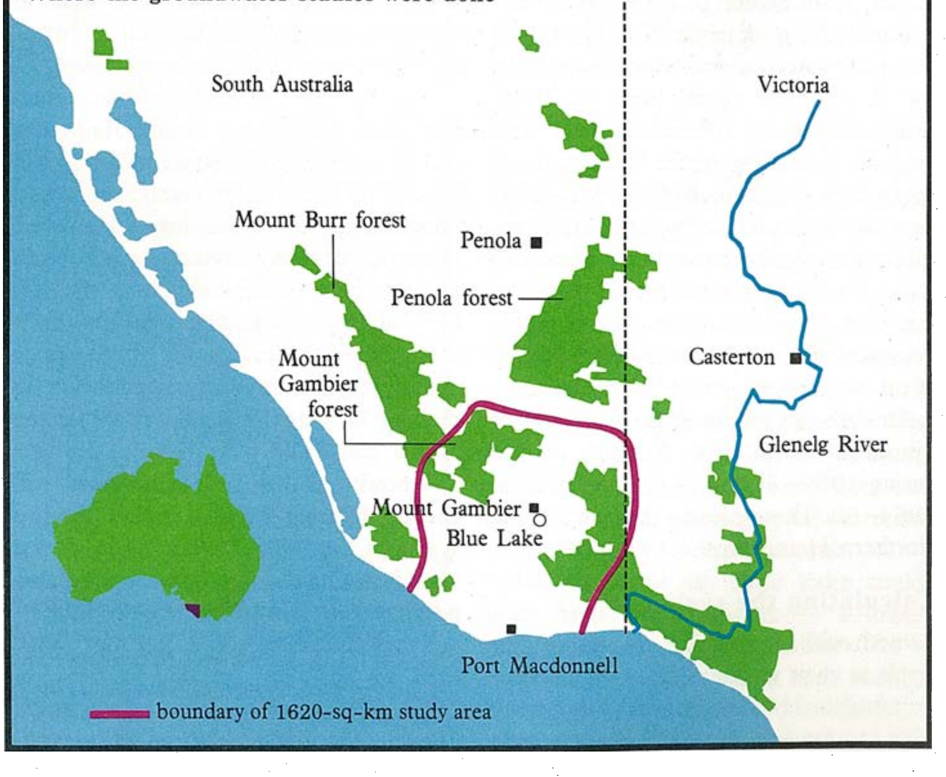
Wines, illumination, headaches

Deducing the age of groundwater samples from their tritium content presented a major difficulty. Dr Allison needed to know how much tritium each year's rainfall contained right back to before nuclear testing began in 1954. But measurements of the tritium content of Australian rain only go back to 1963. Elsewhere in the Southern Hemisphere such records go back another 3 years at Kaitoke, New Zealand, and 5 years at Pretoria, South Africa, but that's all.

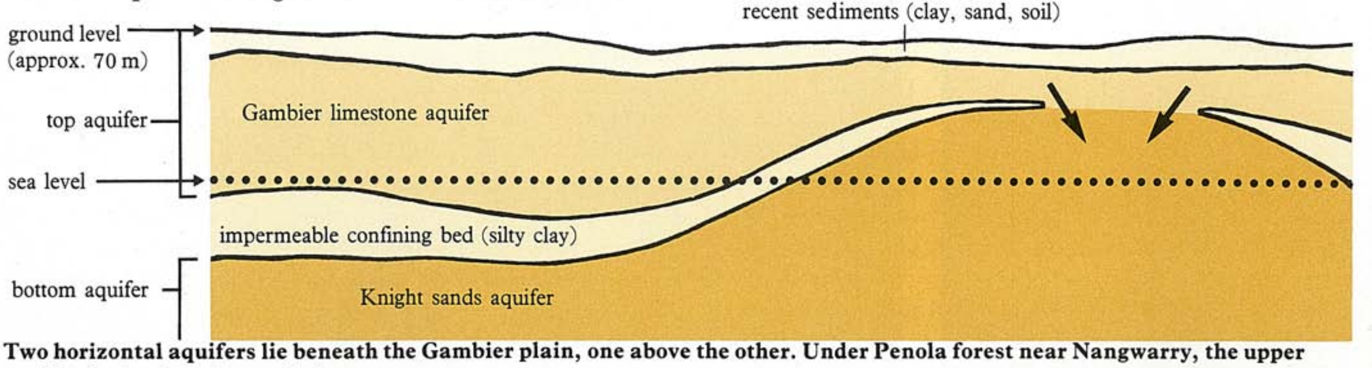
To get round this problem Dr Allison hit upon the idea of analysing South Australian vintage wines made from unirrigated grapes for their tritium content. In this way he could guarantee the ages of his samples for many years back.

Using wines presented some technical difficulties. For example, analysis for tritium had to be done on samples of pure water. Distilling off the alcohol and then

Where the groundwater studies were done



How one aquifer recharges the other near Penola forest



Two horizontal aquifers lie beneath the Gambier plain, one above the other. Under Penola forest near Nangwarry, the upper aquifer drains into the one below.

boiling up with potassium permanganate to break down any organic matter solved that problem.

Interpreting the results also presented some headaches. Not all the water in the grapes from a particular vintage was necessarily of the same age. For example, it looked rather as though the wines from the Barossa Valley contained rain that had fallen several years before the grapes for any particular vintage were harvested.

Information obtained from the State Department of Agriculture on how water moves through the sandy soils of the Barossa Valley confirmed that this indeed should be so. Vines remove water from the soil down to a depth of at least 3 or 4 m. The grapes swell and ripen between January and March — a period when rain is rare. Much of the water in the grapes at that time actually comes from the soil from about 0·9 m depth. Water at this depth in the soils of the Barossa Valley would indeed have fallen as rain several years earlier.

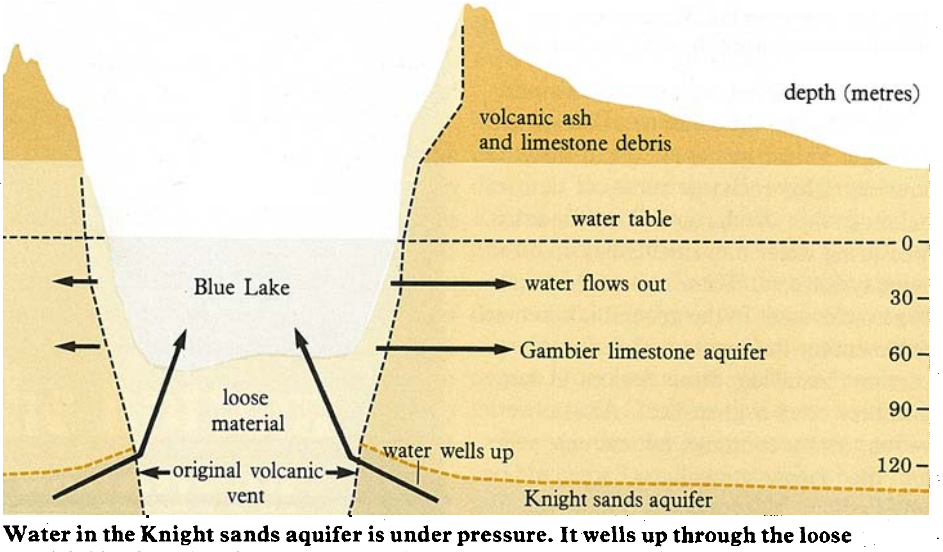
After taking all such factors into account, Dr Allison was able to calculate tritium levels in rainfall back to 1950. Comparing these calculated levels with the measured ones from New Zealand, South Africa, and Adelaide suggested that he really had obtained a reasonably accurate record of tritium levels in rainfall — at least back to the late 1950s when the first rainfall samples were taken. Presumably, therefore, the first 10 years of his wine results could be trusted too.

Dr Allison's results show two peaks of tritium in rain in South Australia — one during 1958–59 and a larger one during 1964–65. These parallel the levels in the Northern Hemisphere.

Calculating the recharge

Armed with knowledge of the tritium levels in each year's rainfall, it's possible to calculate how much tritium has been added to the soil. Finding out how much

The way water enters and leaves Blue Lake



Water in the Knight sands aquifer is under pressure. It wells up through the loose material in the volcanic vent below Blue Lake and flows out through the Gambier limestone aquifer above.

tritium still remains beneath the soil surface is merely a matter of analysing soil cores. Using such soil cores and their knowledge of tritium levels in rainfall, Dr Allison and Mr Hughes were able to calculate the recharge beneath a 1440-sq-km portion of the Gambier plain.

Much of the rain falling on the Gambier plain falls during winter. Rainwater still located near the surface in spring will usually be removed by plants' roots, and returned to the atmosphere. However, rainwater that has already sunk beneath the root zone continues to sink through the soil into the aquifer beneath. Each season's rainwater passes down as a 'surge' of moisture. Thus the rainwater in the soil becomes progressively older the deeper you look.

Knowing that each season's water will contain different levels of tritium, the two scientists were able to work out in several ways how much of the winter rainfall was passing down and recharging the aquifer.

For example, at some sites they managed to pick up the tritium peak of 1964–65. In these cases they could calculate the total amount of tritium, and hence water, stored in the soil between 1964–65 and the time they took their samples. Taking their measurements in March, at the end of the dry season, allowed them to assume that all this water would be going to recharge the Gambier aquifer. Calculating the mean annual recharge was then a simple matter of dividing this total recharge by the number of years that had passed between 1964–65 and the year of sampling.

Soils important

Such methods give the mean annual recharge beneath the particular soil sampled. On the Gambier plain, as elsewhere, more recharge occurs through some soils than through others.

Using a combination of Landsat photographs and a soils map of the area prepared by Mr Dick Blackburn, a colleague in the Division of Soils, Dr Allison and Mr Hughes divided the study area (with Mr Blackburn's help) into four major types of soils. Earlier research in the region had shown that, within areas with the same type of soil, the rate of infiltration of rainwater varied little. So knowing

Water that fell as rain between 1962 and 1966 contains more tritium than any other.

Dr Allison's estimates of annual recharge (in millions of cubic metres per year)

	area (sq km)	mean annual recharge estimates (using chloride)	(using tritium)
sand over heavy clay	157	11·0	7·9
volcanic	21	2·1	2·1
sand over sandy clay	52	7·3	5·2
sand over thin clay on limestone	49	5·1	5·9
terra rossa	60	9·0	7·8
thin sandy loam over limestone	281	39·3	43·5
aeolianite	380	76·0	74·1
skeletal	330	82·5	89·1
forests and swamps	290	0·0	0·0
total	1620	232·3	235·6

Estimated amounts of groundwater leaving the study area

	(millions of cubic metres)
for urban and irrigation use	20
through springs and swamps	170
directly to the sea floor	70
total	260

The two estimates of rainwater entering the groundwater come sufficiently close to balancing others of the amount leaving to indicate a water resource of 230–60 million cubic metres per year under the study area.

the area of each soil type, and the infiltration rate, should make it possible to estimate the mean recharge each year under the whole of the limestone plain.

At their first attempt, the two scientists came up with a recharge figure of 150 million cu m of rainwater per year over all 1440 sq km of the study area.

By comparison, adding existing estimates of groundwater discharge from the same area gave a discharge figure of 202 million cu m per year for this area. Thus there was a discrepancy of 50 million cu m per year between the calculated recharge and discharge.

This difference was explainable. For example, water might be leaking up from the Knight aquifer. However, Dr Allison and Mr Hughes decided to try again. This time they used more sampling sites in a slightly larger study area of 1620 sq km. In addition, they tried another method of estimating the groundwater recharge as well. This involved tracing the amount of chloride in the soil.

Having another go

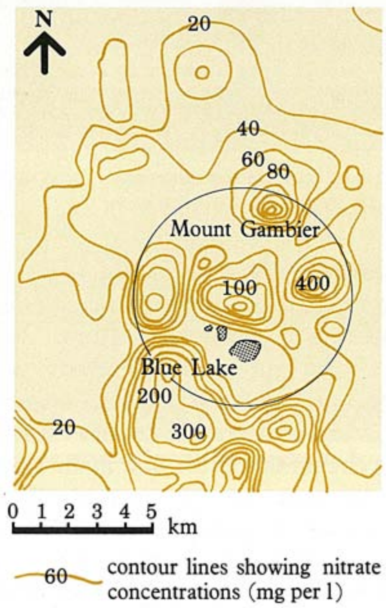
Around Mount Gambier, the scientists assumed, all chloride in the soil-water must come from the soil surface. This surface chloride comes from the sea. It arrives in rain, and also as minute dry particles in the air.

For the well-drained Gambier plain this assumption seemed fair enough. However, in parts of the study area considerable amounts of potassium chloride were being added as fertilizer. Luckily records of fertilizer applications were available for most sampling sites, so these additions could be taken into account.

By knowing the annual rainfall and how much salt was being deposited at the soil surface, the two researchers were able to calculate the amount of water passing through the soil by measuring the chloride concentration. In this way they estimated the mean annual recharge beneath the 1620-sq-km study area to be 230 million cu m of water. Using soil tritium concentrations yielded an estimate of 240 million cu m.

By comparison, a revised estimate of groundwater discharge from the same area came to 260 million cu m per year — a very tolerably close agreement. (Over the slightly smaller area originally used, the figure for mean annual recharge would have been 170 million cu m, compared with the 150 million cu m estimated at the first attempt.)

Nitrate levels in groundwater near Blue Lake



The high nitrate concentrations surround known nitrate sources. Blue Lake will remain free of nitrate pollution as long as the city of Mount Gambier doesn't remove its waters faster than the Knight sands aquifer recharges them.

Blue Lake's future?

And how does all this affect Blue Lake? Dr Allison points out that, although ample groundwater is available in the study area for irrigation and urban use, the actual location of extraction points would have to be chosen with care. Rapidly pumping water out of the aquifer would lower the local water table, which governs the level of Blue Lake. For this reason it would be desirable for pumping points to be located as far away from the lake as possible, preferably downstream — in other words, near the coast.

But that's not all. Blue Lake could suffer from two problems — a lower water level, and nitrate pollution.

Nitrate pollution would both reduce the quality of the water for drinking purposes in Mount Gambier itself and, if bad enough, cause green soupy blooms of algae to develop on the lake's surface during summer (see 'Ammonia-strippers on trial' on page 19).

To date, nitrate levels in the lake have remained low. However, nearby nitrate and bacterial pollution of the aquifer has been causing concern. The nitrates come from two sources — from fertilizers applied to farm land in the vicinity, and from Mount Gambier itself. Local industry, for example, has for years discharged its liquid wastes through bore holes into underground caves beneath the town.

By 1972, the situation had become so serious that the South Australian Department of Mines carried out a survey to assess the extent of pollution in the Gambier limestone aquifer in and around the city.

The survey revealed nitrate concentrations as high as 490 milligrams per litre — that's 10 times the safe upper limit of 45 mg per l generally accepted for human consumption. Obviously, if the lake is to remain clean, the authorities must know exactly where its waters come from and exactly what controls its level.

The State Engineering and Water Supply therefore financed Mr Jeff Turner, a Ph.D. student at Flinders University, to sort these questions out. He too was located at the CSIRO Division of Soils, Adelaide.

Water wells up

Blue Lake sits in a volcanic cone whose vent passes right through the upper Gambier limestone aquifer and the lower Knight sands one. So water from the lower aquifer can flow into the lake through the loose debris that now fills the vent. Using a number of techniques including Dr Allison's tritium method and carbon dating of the carbonate in the groundwater, Mr Turner succeeded in 'ageing' the water in the lake. This told him whether most of it came from the upper aquifer or the lower one.

It turned out that something like 80% of the lake's water comes from the deeper aquifer, which may seem surprising. But the lower Knight sands aquifer is an enclosed 'pool' under pressure and, if unconfined, its water level would rise 9·4 m above that of the Gambier limestone aquifer that lies above it.

For much of the year, it seems, water flows up into the lake from the lower aquifer and leaves through the higher one. As long as this happens nobody need worry about nitrate pollution in the higher aquifer getting into the lake.

Bottled wines— Dr Allison's source of old water samples.

Nuclear tests are the sources of most of the tritium in our environment.

Pollution risk

However, during the peak summer months of December to April, more water is pumped out of Blue Lake to supply the town of Mount Gambier than enters it from the lower aquifer. Under these circumstances the flow in the Gambier limestone one is reversed. Water now flows out of this upper aquifer into the lake.

The risk that nitrate pollution of the lake may occur during this summer period is very real. Indeed, between March and May last year the lake's surface was located at the centre of a cone-shaped depression in the water table of the Gambier limestone aquifer. Mr Turner found this out by observing the changes in the water levels of 30 bore holes drilled by the State Department of Mines within a 2-mile radius of the city. Presumably during this period, water was flowing into the lake from this upper aquifer.

And what about extracting water for irrigation? Obviously, lowering the water table would lower the level of the lake.

But there is another complication. Mention has already been made of the fact that the lower Knight aquifer is recharged only from the Gambier limestone one above it. This happens in at least two locations near Nangwarry, some 30 km to the north. Here both the Knight and Gambier limestone aquifers are located somewhat higher than they are at Mount Gambier, which explains where the Knight sands aquifer's 9·4-metre head comes from. If water taken for irrigation reduces recharge of the Knight aquifer, then a loss of pressure will result and flow into Blue Lake will be reduced.

With mismanagement, polluted water from the Gambier limestone aquifer could flow into the lake permanently, with unfortunate consequences. As Mount Gambier expands, the risk will increase unless corrective steps are taken.

More about the topic

Estimation of groundwater inflow to small lakes. G. B. Allison, J. V. Turner, and J. W. Holmes. *Proceedings of International Atomic Energy Agency Symposium on Isotope Techniques in Lake Hydrology, Vienna* (in press).

The use of environmental chloride and tritium to estimate total recharge to an unconfined aquifer. G. B. Allison and M. W. Hughes. *Australian Journal of Soil Research*, 1978, **16** (in press).

The history of tritium fallout in southern Australia as inferred from rainfall and wine samples. G. B. Allison and M. W. Hughes. *Earth and Planetary Science Letters*, 1977, **36**, 334–40.

Estimation of the water resources of a portion of the Gambier plain, South Australia, using a new method for evaluating local recharge. G. B. Allison. *Proceedings of the Institution of Engineers Symposium on Hydrology, Armidale, May 1975*, 1975.

Comparison of recharge to groundwater under pasture and forest using environmental tritium. G. B. Allison and M. W. Hughes. *Journal of Hydrology*, 1972, **17**, 81–95.

Land use and water tables. *Rural Research* No. 78, 1972.