

Trees, water, and salt — a fine balance

When French explorer Louis de Freycinet touched Western Australia's coastline at Shark Bay in 1818, fresh water was so hard to find that his party wondered whether the Aborigines drank sea-water.

Over much of this dry State, saline water is part of the natural environment.

Indeed, the water the Aborigines drank — like that consumed by today's inhabitants near Perth — did contain some sea-salt (although much less than the ocean does). Rain here carries a modicum of salt (mainly sodium chloride) picked up from sea spray; the salt is later deposited on land at rates of 5–30 g per square metre per year. Scientists even find small quantities of salt falling out of clear blue skies.

The salt builds up in the soil, and levels of 50–100 kg per sq. m are most common in the south-west of the State. Normally, in the naturally vegetated condition, the amount of salt coming in from above is matched by the quantity departing via streams and groundwater seepage, and all is well with the world.

The difficulty arises when the pristine environment suffers human disturbance. We now know that removing native vegetation and replacing it with pasture alters the water balance in the soil: because of reduced evaporation and transpiration from pasture plants, groundwater levels rise, salt is mobilised, and stream salinity increases. This process, called secondary salinisation, can lead to salt exported by streams exceeding imports by a factor of 20. Calculations suggest this state of affairs could continue for hundreds of years before a new balance is struck.

In the south-western corner of the State, 36% of the total divertible water resources are now classified as brackish — containing 1000–3000 mg total soluble solids per L — or saline — having more than 3000 mg T.S.S. per L. (The desirable maximum for water supplies is 500 mg per L; sea-water contains about 30 000 mg per L.) Moreover, it has been estimated that a further 16% of currently marginal-quality resources are at risk of becoming brackish if catchment management measures — in addition to clearing bans — aren't initiated or continued. A rising trend in stream salinity following clearing was first noticed

early this century, and has continued ever since.

Dr Adrian Peck, until recently a hydrologist with the CSIRO Division of Water Resources in Perth, relates that secondary salinity probably contributed to the breakdown of the Sumerian civilisation around 2500 B.C. He believes that the salinisation of water resources could seriously affect the welfare of Western Australians in the same way as it now affects the lives of the inhabitants of parts of India, Pakistan, China, and Thailand.

For example, the salinity of the Blackwood River, the largest one within 2000 km of Perth, has increased threefold over the last 50 years — its water is now of secondary quality. That's an environmental catastrophe, in his view, in that the Blackwood could otherwise have made a major contribution to the water needs of the south-west.

When salt kills vegetation, the way is opened to soil erosion.



Like the fate of the frog that died in the saucepan of water, the problem owes much to a slow build-up. The frog lacked the sudden stimulus to jump out of the steadily warming water while it could, and we and our forefathers lacked the long perspective that would have stopped excessive forest clearing in time to prevent water becoming too salty to use.

In some cases of dryland salinity, clearing of land almost a century ago may only now be producing problems. The area of salted land under dryland (non-irrigated) agriculture in Australia is expected to double by the year 2000. And, according to a recent report by the Western Australian government's select committee on salinity, the potential for salinisation in the State is about 10 times the current extent.

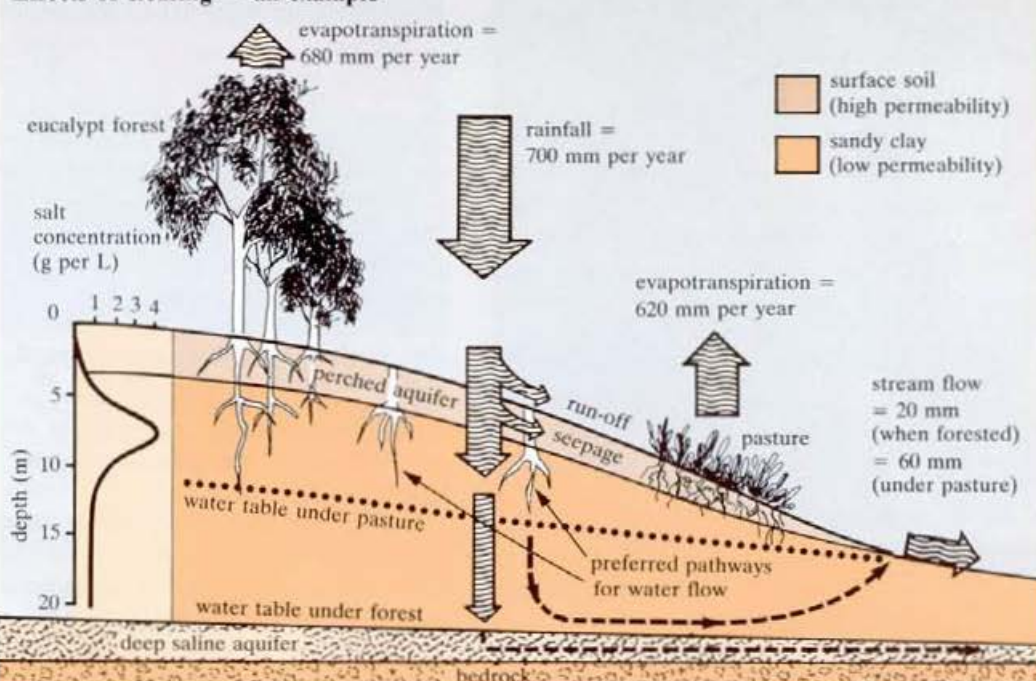
In the troubled Great Southern region, the report estimates that 30–50% of cleared land — up to 9300 sq. km — could become salt-affected in less than 20 years.

Collie River basin

A good example of one such area with a mounting salinity problem is the Collie River basin in the south-west. By 1976, when about one-quarter of the basin's 2800 sq. km had been cleared, domestic water supply from Wellington Dam, the Collie's main impoundment, had exceeded desirable salinity standards and the Western Australian government had introduced a ban on clearing (except with a licence) within the area.



Effects of clearing — an example



Wellington Dam is a vital resource, supplying water to 50 sq. km of irrigated land (mostly dairy farms) on the coast near Bunbury, and to many farms and townships between Perth and Albany. A continued rise in the catchment's salt levels gives cause for real concern.

In 1973, scientists from the CSIRO Division of Water Resources and the Water Resources Section of the Public Works Department (now the Hydrology Branch of the Water Authority of Western Australia) began an intensive study in the Collie River basin with the aim of getting a good grasp on how vegetation, hydrology, and salinity are related. They were assisted by the Forests Department (now part of the Department of Conservation and Land Management) and the Department of Agriculture.

The study, with funding from the Australian Water Resources Council, involved the close monitoring of five catchments within the basin — a matched pair (Wights and Salmon) in a high-rainfall area (about 1200 mm per year), and a trio of similar ones (Lemon, Ernies, and Dons) in a lower-rainfall zone (800 mm per year). The map on page 4 shows their locations.

After 3 years of monitoring to establish a baseline, one of the matched pair was completely cleared and partial clearing strategies were applied to two of the trio. This article will summarise what the scientists learnt as they studied the response of the catchments over more than 10 years.

A tale of five catchments

All five catchments, ranging from 82 ha to 350 ha, are located in the Darling Range within 30 km of the town of Collie. They were surrounded by State forest, and at the beginning of the experiment they were all

Clearing reduces evapotranspiration, so more water reaches the water table. This rises, carrying salt into the stream.

covered with open jarrah woodland. In most respects they were typical of the Darling Range catchments, which together supply 40% of Perth's water.

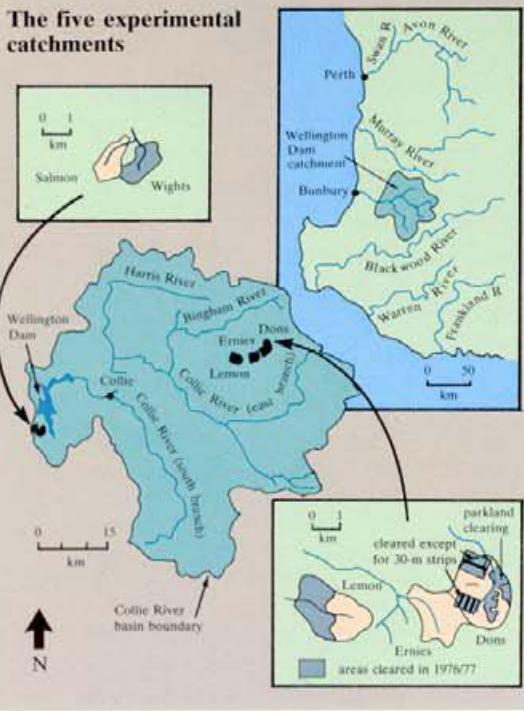
The scientists installed more than a dozen rain gauges and scores of piezometers (bores to monitor groundwater levels). They analysed the recovered soil cores for salt and water content; isotopic composition of the water was also measured. Installing V-shaped weirs across water-courses and recording the height of water spilling over these gave them a measure of stream flow out of the catchments.

Using neutron moisture meters, the hydrologists measured the amount of water held in the soil above the water table. They calculated the input of salt to the catchment by measuring the salt content of rain, and deduced the amount of salt leaving from measurements of stream salinity.

We lacked the long perspective that would have stopped excessive forest clearing in time.

Instrumentation was completed by 1974, and the trees were cleared in the summer of 1976/77 over the whole of Wights catchment and half of Lemon, where sheep grazing then commenced on a grass and clover pasture. Wheat, lupins, and barley were planted in the 38% of Dons catchment that was also cleared, while Salmon and

The five experimental catchments



In 1976/77, after 2-3 years of 'baseline' monitoring, Wights catchment was totally cleared, half of Lemon was cleared, and parts of Dons were partially cleared. Salmon and Ernies continued as control catchments.

Ernies remained as the uncleared control catchments.

Since Wights catchment received the most radical treatment, and was in a higher-rainfall area, it suffered the most marked hydrological repercussions. For the sake of brevity, most of what follows will describe the fate of this catchment.

What happened?

The effects of clearing were immediate. Stream flow increased and, probably for the first time ever, the stream draining Wights became permanent. Within 3 years after clearing, the total annual flow grew to an amount 4-7 times greater than it had been before — instead of the 7% of rainfall reaching the stream in 1975, 48% did so in 1983. Peak flows after storms also increased — to 5-50 times what they had been before. After one severe storm in 1985, the peak discharge for the day in Wights was 120 times bigger than that recorded for the

After clearing, not only did average stream flow increase, but the stream, once dry in summer, became permanent.

Potential for salinisation in the south-west

region	area 1984 (ha)	potential area (ha)	time to develop (years)
Northern	86 400	600 000	20
Central	91 974	656 000	50-200
Great Southern	62 532	930 000	20
South West	3 090	96 000	20
South Coast	9 217	165 000	10-30
	253 213	2 447 000	

The Western Australian Department of Agriculture estimates that the area of salinised land in the South West Land Division could increase ten-fold over coming decades if water tables keep rising at current rates.

adjacent uncleared (and similarly sized) Salmon catchment.

For the partially cleared catchments, peak flows generally increased by a factor of less than five.

The export of salt from Wights increased substantially after clearing. Whereas import of salt from the sky remained reasonably constant at about 13 g of T.S.S. per sq. m per year, by 1983 the stream was carrying away 15 times this figure at an average salinity of 370 mg of T.S.S. per L, 2-3 times higher than it would have been if the catchment had remained forested.

And, as we shall see, there was good reason to think that salt levels had only started to rise. The data show that, although a catchment's water balance may quickly reach a new equilibrium after clearing, the salt balance takes many years to readjust — and then, because so much salt is stored, it takes many decades, perhaps even centuries, for salt exports to decline again to levels matching imports.

Surface soils in the area are porous, and it's rare for rainfall to be heavy enough to create direct surface run-off, and then this only occurs in small areas. Clearing increased the volume of surface run-off by a factor of 15, but even so this represented only about 20% of the post-clearing stream flow, the scientists estimate.

This figure comes from comparing differences in stream flow between the cleared and uncleared catchments. Some 80% of the additional water was discharged at times of low flow (less than 460 L per second); this leads the scientists to identify

this proportion as passing through the groundwater system.

A similar analysis for salt suggests that 97% of the additional salt in the stream comes from groundwater.

Salt and water pathways

Further detailed analysis allowed the scientists to pin down the source of the salt much more precisely, and gives us a revealing insight into what is going on beneath the surface.

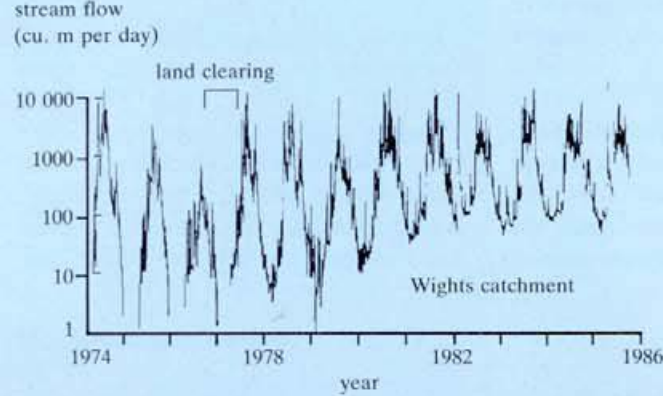
First we need to understand that, in the south-west of Western Australia, a dual aquifer system is the norm. Near the surface, in the porous, coarse-textured soil, we find an unconfined aquifer that comes and goes according to the abundance of recent rainfall. This shallow 'perched' aquifer, up to about 3 m thick, sits above a finer-textured clay-like layer in which we usually find a perennial and more saline groundwater system.

Measurement of Wights in 1980 points to an interesting conclusion. While the bulk of the water in the stream (56%) passed through the shallow perched groundwater layer (and 24% came via the deeper groundwater system), the picture for salt was reversed. Most of the salt in the stream (84%) originated from the deep system (and 16% from the perched one).

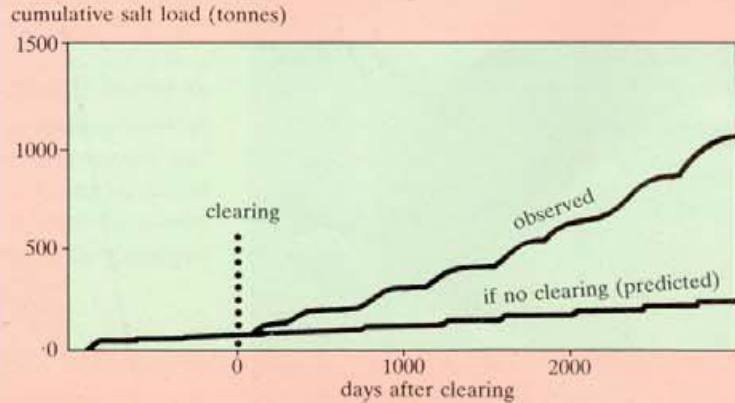
Differences in the salinity of the two layers can't account for this contrast. And, whereas the surface layer of Wights catchment stored a total of about 180 tonnes of soluble salts at the time of clearing, in the 7 years after clearing more than 720 tonnes was carried away in the stream — without significantly changing the salinity profile.

Hundreds of tonnes of extra salt were carried by the stream draining Wights catchment after clearing.

Clearing increases stream flow



Clearing increases salt exports





Measuring the rate of water loss from a forest understorey. Similar measurements were done on individual trees, pasture, and crops.

The researchers came to the conclusion that the source of the salt is the deep perennial groundwater system, the perched aquifer is the transfer station, and the stream is the destination.

Some careful detective work with natural water isotopes, described later, backs up this conclusion.

Measurements showed how — with rising water tables and sloping topography — this could happen. In March 1984, piezometers showed that the pressure in the deep aquifer was enough to drive water into the perched aquifer over some 25% of the catchment's area. Indeed, over about 15% of the catchment, the pressure could drive water to the surface. This was an enormous change compared with 1974, when less than 1% of the catchment (0.5 ha) had the potential to develop seepage.

These areas were the sources that kept the stream flowing even in summer; indeed the stream's average salinity during summer virtually matched the salt concentration of

the deep groundwater (about 1000 mg of T.S.S. per L).

Of course, because of capillary action, soil can become moist for a metre or two above where it's saturated. Although moist areas don't contribute directly to stream flow, indirectly they do so by diminishing infiltration when it's raining, and hence increasing run-off. Whereas only 5% of the surface of Wights was less than 2 m above the piezometer level before clearing, 24% was by 1984.

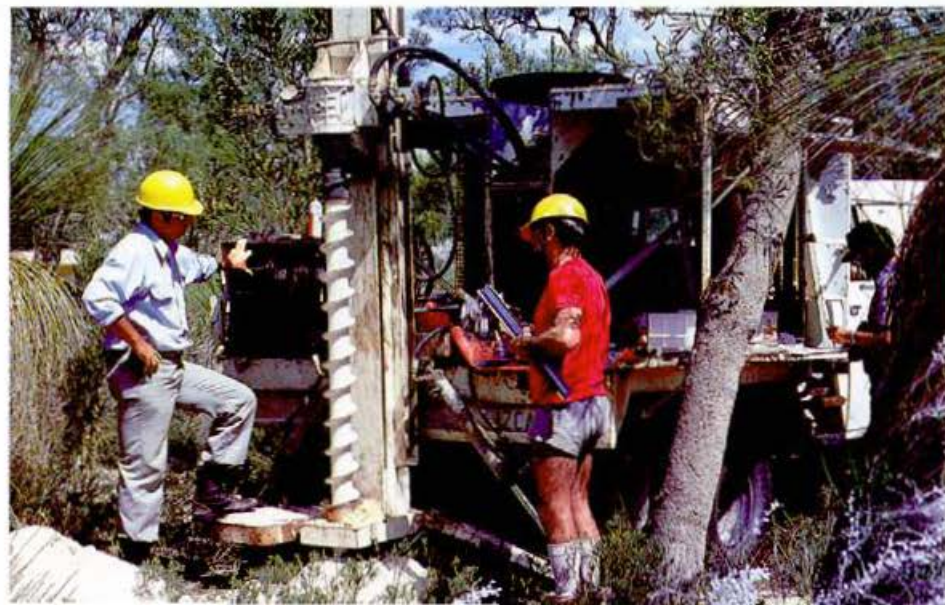
A neutron moisture meter confirmed what the piezometers indicated. Within 2 years of the changeover from forest to pasture, it showed a significant increase in the amount of water held in unsaturated soil.

Over the whole of Wights catchment, the minimum (summertime) amount of water stored in unsaturated soil increased by the equivalent of 220 mm rainfall in the first year, and another 58 mm in the second. The additional 220 mm represents 24% of the previous year's rainfall. At one site, the minimum summer water content at 4–6 m depth after clearing was almost the same as the winter maximum before clearing took place.

While a few areas showed increased water content from 0 to 2 m depth, the general picture was for increases to be concentrated in the layer 2–6 m down. The reason, of course, for a lack of surface increase was that the roots of pasture plants were at work extracting moisture from the top metre or so.

In fact, the difference between the action of pasture roots and that of eucalypt roots explains much of the changed hydrology following clearing. Tree roots extend to 6 m and more; some investigations have shown jarrah roots stretching down to a remarkable 40 m. The present study showed that about half of the extra stream

Taking core samples. A salt profile can be constructed by analysing them piece by piece.



flow resulting from forest clearing comes from the diminished ability of pasture to extract moisture and transpire it to the air.

The other half of the increased flow came from eliminating, by clearing, loss of water by a process that hydrologists call interception. Trees catch, or intercept, rain in their foliage, and this soon evaporates. Well-grazed pasture grasses hold virtually no rain; instead, water that would otherwise have been intercepted and evaporated finds its way into the soil and eventually into the stream.

Prisoners of time

As extra water soaked in, the water table inevitably rose. In the fully cleared catchment the initial rate of rise was at least 2.6 m per year (an extra 65 mm of recharge, or 6% of annual rainfall, could have been enough to do this) whereas in the partially cleared ones the annual rise was a smaller 0.9 m.

Superimposed on the rise was an annual fluctuation usually amounting to 1–4 m. If the groundwater store acted like a bucket, you might expect the peaks to occur many months after October — when the winter rains have finished and the water has had time to soak slowly down through the clay.

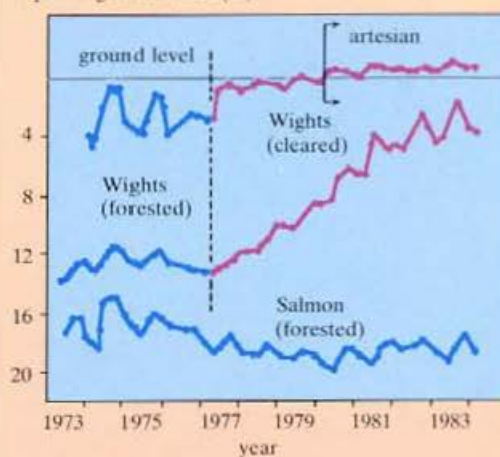
Instead, the hydrologists recorded maximum water-table levels around October. The earlier-than-expected peak is evidence that the bucket is very 'leaky' — a circumstance that shifts the maximum level towards times of greatest recharge rates (July).

By carefully recording the dynamics of the water table in response to rainfall, the scientists could calculate precise figures for percolation times and leakage rates. Their measurements indicate that the percolation rate is much faster than you would expect

Immediately after Wights catchment was cleared in 1977, groundwater levels started rising. In the matched forested catchment (Salmon) there was little change over the years.

Groundwater rises after clearing

depth to groundwater (m)



Trees as groundwater pumps

If bulldozing of trees has had such a clear effect in raising water tables, might not replanting them be the best remedy for salinity problems?

Of course, that's true where wholesale replanting is possible.

For example, early this century, trees in parts of the Helena River catchment were ringbarked to increase the water volume flowing into the Mundaring Weir (the water source for the Kalgoorlie goldfields). Unfortunately, salinity levels rose along with water yields.

Reforestation was tried as an antidote. It worked, and today the goldfields region still gets its water from Mundaring. Parts of the Collie River basin are now also being reforested as a step towards reducing salinity in Wellington reservoir.

But we can't reforest everything and still have farmland left to farm. Can a smaller antidote do the trick?

The Collie catchment studies have shown that, under pasture, the amount of rainfall reaching groundwater is only 25–75 mm per year. This is small, and suggests that only a small strategic part of a farm may need to be planted with trees to prevent the groundwater level rising.

In co-operation with government departments, Dr Eric Greenwood and colleagues

at the CSIRO Division of Water Resources have been conducting experiments to measure the capacity of trees to pump groundwater from the root zone and transpire it through their leaves.

They have wrapped individual trees in transparent plastic, pumped air through the package at a known rate, and measured the water lost as humidity in the air. They have found that the transpiration rate depends mainly on depth of the roots, depth to the water table, salinity and oxygen content of the groundwater, and leafiness of the canopy.

Certain eucalypts were outstanding. In an 800-mm-rainfall zone, plantations of *Eucalyptus globulus* (blue gum) and *E. cladocalyx* (sugar gum) could annually dissipate 2–4 times the amount of rain that fell on them, compared with only 0.6 times for pasture.

Not so long ago, farmers got tax deductions for clearing; now incentives are given for fencing off surviving bush, and for replanting. This year, Western Australian farmers will plant about 12 million trees.

The hydraulic role of vegetation in the development and reclamation of dryland salinity. E.A.N. Greenwood. In 'The Reconstruction of Disturbed Arid



First comes the clearing, next comes the salt.

Lands', ed. E.B. Allen. (Westview Press: Boulder 1988.)

Water use by trees and shrubs for lowering saline groundwater. E.A.N. Greenwood. *Reclamation and Revegetation Research*, 1986, 5, 423–34.

Differences in annual evaporation between grazed pasture and *Eucalyptus* species in plantations on a saline farm catchment. E.A.N. Greenwood, L. Klein, J.D. Beresford, and G.D. Watson. *Journal of Hydrology*, 1985, 78, 261–78.

for clay, and this anomaly is strong evidence for the existence of cracks and root channels that let water trickle down rapidly to the water table. We will point to the significance of these preferred water pathways for salt movement later on.

The significance of the other derived figure — the 'leakage' rate, or outflow via streams — connects with predictions of

After the scientists had measured the salt profile in a core taken from the forested Salmon catchment, they calculated the net water flux that could have given rise to it. A build-up of salt at a certain depth is a sign that the downward flow of water has diminished — because of uptake by tree roots.

what the long-term fate of a catchment might be. For example, although increases in stream flow began only a year after clearing Wights catchment, and soil water content in the top 6 m appeared to have stabilised within a few years, 7 years later stream flow as a percentage of rainfall was still increasing steadily, closely matching the expansion of the groundwater discharge area.

After 7 years, discharge from the stream was about 80% of recharge, and it's currently about 90%. For other aspects of water and salt movement, balance was even slower to achieve — it takes about 5 years for the unsaturated zone to achieve a new

equilibrium, and 20 years or more for the deep groundwater system to do so. In the lower-rainfall-zone catchments, the time factors are larger still.

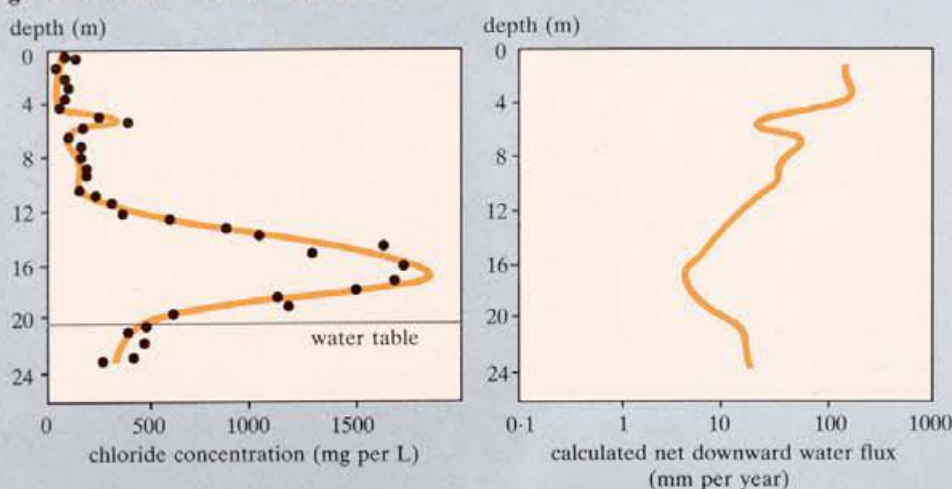
For example, in Lemon and Dons catchments, the scientists predict a 12-year delay after clearing (about now) before the deep groundwater starts to affect stream flow, and it will take until about the year 2010, they expect, to establish a new equilibrium in stream flow. These delays of 10–40 years explain why salinity levels in Wellington Dam only became a problem in the 1970s, whereas much of the clearing in the area took place decades earlier.

Once a new water balance has been struck, salt can readjust too, but this is a much longer process again.

In Wights catchment, examination of salinity profiles tells us that an average 4300 g of salt lies beneath each square metre of the surface. Over the last 3 years of measurement, about 90 g of salt per sq. m was lost from the catchment, so if that rate holds constant it will take some 50 years for all the salt to be leached away.

Of course, the salt loss won't remain constant, but will taper off. It's better to

High salt content — low water flux



speak of a half-life of salt dissipation, and this is likely to be about 30 years for Wights. For the drier catchments, where salt levels are higher (22 000 g per sq. m) and a new water balance takes longer to achieve, a half-life of 500 years is expected. On the basis of these figures, the salt problem induced by clearing will be with Western Australians for a long time.

Channels through the clay

We saw earlier that, because clay is fairly impermeable, one would expect that water should take several months to percolate down to the water table. Below 5m depth, recharge rates of 2–5 mm per year (for western catchments) and 0–4 mm per year (for eastern ones) are inferred from analysis of salt profiles.

Yet, at many sites, the water table — surprisingly — was seen to respond in a matter of hours. Rates of water movement of about 1 m per hour could only be explained by the existence of isolated cracks and root channels in the clay. These preferred water pathways make it impossible for hydrologists to calculate the average permeability of the landscape by drilling a number of 'representative' soil cores. In the present exercise, the scientists discovered that the hydraulic conductivity of the soil varied very markedly from one bore hole to another — for example, values for two bores only 5 m apart could register as 2 and 100 mm per year.

At one bore hole, which must have been located — fortuitously — right on top of a channel, a groundwater 'mound' a few metres high and several metres across built up within 12 hours of heavy rain, and disappeared again over the next 2–4 days.

The significance of these preferred channels is that water flowing in them has limited opportunity to leach the salt that is mainly held within the relatively impermeable clay. The salt therefore stays in the upper reaches of the soil profile until such time as the water table rises to flood the salty region. This is one reason why salt takes so long to be cleared from the landscape.

Water carries natural tracers

Up to now, hydrologists have had to infer most of the key quantities they sought — for example, they calculated recharge rates from considerations of rainfall and stream flow.

Recently, however, they have begun to use naturally occurring tracers — tritium, deuterium, oxygen-18, and chloride ion — to more directly measure the flow of water through the ground.

Chloride ion is simply one part of the sodium chloride that has built up in the soil after a journey from the sea. From a fairly constant concentration in raindrops, the salt concentration in the soil varies enormously with depth, we find. Why?

One major reason is that tree roots suck up water but not much salt. A bulge in the

salt profile — normally at 5–10 m depth — indicates where tree roots have been most active. Every winter, rains supply moisture to the root zone, and every summer the roots dry it out again in a sequence that has been repeated thousands of times.

Another factor influencing chloride concentration is the rate at which water flows

Planting trees for Wellington Dam's sake

Wellington Dam, the main impoundment in the Collie River catchment, has a growing salinity problem; one counter-measure — reforestation — may just keep water quality acceptable.

Despite a ban on further clearing in 1976, when about a quarter of the basin's 2800 sq. km had been cleared, salinity levels have continued to move upward. As the graph shows, they are presently hovering about 1000 mg T.S.S. per L — on the borderline between 'marginal' and 'brackish'. Will the upward trend continue?

The Collie catchment studies have allowed hydrologists to calculate future salinity levels more accurately. Results have confirmed estimates made at the time of the clearing-control legislation that, if nothing else were done, the quality of water for both irrigation and town use would become unacceptable — particularly in dry years.

They also confirm the value of a reforestation program that began in 1979. Each year, the Water Authority of Western Australia (WAWA) plants an extra 7–8 sq. km to trees. More than 50 sq. km of cleared farmland have now been replanted with a variety of eucalypts.

In accordance with the hydrological findings, planting has been done in the drier (saltier) third of the catchment, and focuses on the floors and lower slopes of valleys. Under the current program, some 80 sq. km will be reforested by the early 1990s, at an expected cost of \$15 million.

Water Authority hydrologists have recorded reductions in groundwater levels under many of the monitored plantings.

Falls have been largest where the planted areas covered 30% or more of the cleared land. Plantings over less than 20% of the landscape have, to date, shown little effect.

The hydrologists expect that the trees will reduce groundwater discharge by about 70% over the most troublesome 500 sq. km. Ultimately, salinity should stabilise at about 950 mg T.S.S. per L — a just-acceptable level — and 200 mg better than it otherwise would have been.

Of course, while they may do the trick, trees are slow to take effect. They won't significantly reduce salinity levels until the mid to late 1990s. However, their effect should be sufficient to keep the water good enough for irrigation on the coastal plain (90% of Wellington Dam's water is used this way).

But 10% of supply is drinking water for towns in the southern wheat belt, and the water is already too saline for that to continue.

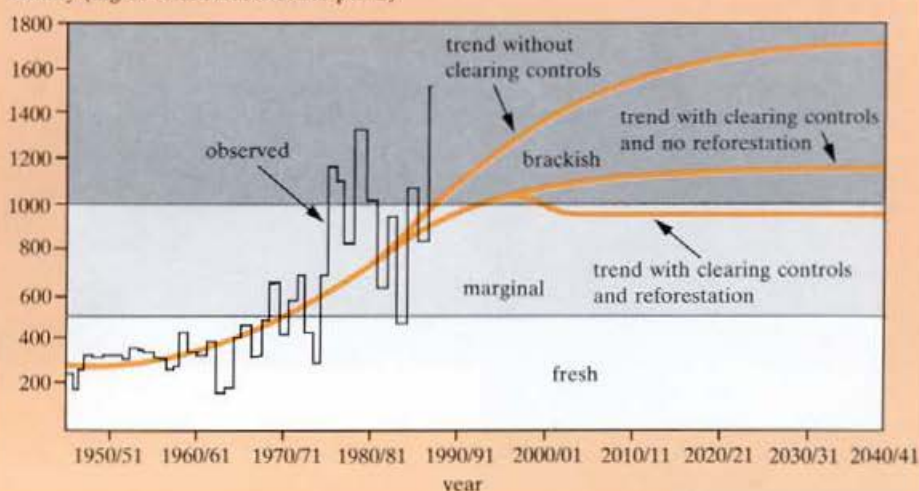
A new source is needed, and by 1991 fresh water (250 mg T.S.S. per L) will be coming from the Harris Dam, an impoundment scheme under way on a forested tributary of the Collie.

WAWA is presently considering whether to expand the reforestation program, with the aim of returning all of Wellington Dam's water to drinking quality.

Salinity levels of inflow into Wellington Dam, the main impoundment on the Collie River, are rising. The trend is typical of many streams in the south-west. Currently 24% of the catchment is cleared; controls now in place will limit further clearing.

Rising salinity in Wellington Dam

salinity (mg of total soluble solids per L)



The scientific team

Division of Water Resources:

Dr Adrian Peck — project leader (now a groundwater consultant with Rockwater Pty Ltd, Subiaco, W.A.)
Mr David Williamson
Dr Munna Sharma
Dr Jeffery Turner
Mr Eric Bettenay (now retired)
Mr Colin Johnston
Dr Duncan Macpherson
Mr Robin Barron

Water Authority of Western Australia:

Mr Robert Stokes
Mr Greg Hookey (now in private industry)
Mr John Ruprecht
Mr Ian Loh

through the bulge, flushing salt downwards. From a given profile of chloride concentration, scientists can work out the relative flux of water at each depth (see the diagram on page 6 for an example).

When hydrologists did this for the present study, they found out just how significant cracks and root channels were. Only a very small fraction — 0.05% to 0.4% — of rainfall reaches the water table through the bulk of the unsaturated soil. The rest bypasses that route through the preferred water pathways (which occupy a very small proportion of the landscape).

A channel 2 mm in diameter, they calculate, could transport as much water as 37 sq. m of its surrounding clay matrix.

Preferred channels also explain a puzzling result involving radioactive tritium. Tritium — hydrogen-3 — has been present in water in small quantities since the 1950s, when nuclear weapons were tested in the atmosphere. The scientists used a liquid scintillation counter to detect its decay in groundwater samples.

The puzzle concerned the detection of tritium at depths of up to 6 m, indicating that rain from within the last 30 years had

Many of the sudden changes in the deuterium content of the stream can be traced back to deuterium anomalies in particular falls of rain some time previously.

reached this depth. Yet, if the water flux figures derived from chloride abundance were to be believed, rain should take some 1700 years to get that far.

The disagreement vanishes if we see water and salt as, to a fair degree, preferring to travel different paths in their tortuous journey through the soil. Salt, discriminated against by tree roots, tends to end up in clay just below the root zone, while water tends to trickle down through cracks into the deep permanent groundwater system.

Isotopic signatures

A mass spectrometer is the latest addition to the hydrologist's tool-box. With it the researcher can identify the isotopic signature of individual rainfall events and trace the path of the rain as it percolates into the ground and into a stream.

The signature the hydrologist seeks derives from the the varying proportions of deuterium (hydrogen-2) and oxygen-18 contained in water samples. The variation comes about because each fall of rain originates from water vapour that has evaporated and condensed under a unique temperature pattern; temperature determines the isotopic mixture of water molecules because each isotope possesses slightly different volatility.

For example, the rain that fell on a forested catchment, Salmon, on May 25, 1985, was depleted in oxygen-18 by 0.4% (compared with standard water) and in deuterium by 1.8%. Water sampled from the stream at that time had a very similar isotopic signature. The stream's isotopic composition then quickly changed, veering towards the signature of a previous rainfall on April 9.

Then on June 9, more rain came, and the stream's isotopes repeated this pattern. As the season progressed, it became harder to distinguish individual rainfall events in the stream. It seems that, as the shallow groundwater store fills up, later rain becomes mixed and diluted with a bigger store. Indeed, isotope analysis of water taken from shallow bores showed profiles that were remarkably uniform, indicating that the individual falls had, over a year, become well mixed in the shallow groundwater.

Deep groundwater was also very uniform, but in this case the degree of mixing observed entailed the mingling of water from several years' rain.

The isotopic signatures of shallow and deep groundwaters clearly differed, and the researchers found that the stream-flow isotopes matched the shallow groundwater

A whole valley full of salt.



isotopes quite closely. For four well-identified falls of rain, between 60 and 95% of the stream flow originated from water stored in shallow groundwater.

Mathematically correlating a series of rain and stream isotopes gave an average time lag between the two of 20–50 days. The 'age' of the stream water tended to decrease after rain and then increase again.

Precious water

We now have, for the first time, a complete picture of the ins and outs of salt-prone catchments. We also have a measure of the difference that vegetation makes to the water budget, and this recharge figure is the key quantity all salinity countermeasures must try to neutralise. The effectiveness of one approach to reversing the salinity problem — replanting trees — is discussed in the box on page 6.

But whether we plant trees, use engineering remedies, or change agricultural practices, we can now appreciate that fresh water in the Darling Range — a precious commodity — hangs upon an especially fine balance.

Andrew Bell

More about the topic

Journal of Hydrology, 1987, **94**, 1–198.

(Special issue containing ten papers on the hydrology of five experimental catchments in the Collie River basin.)
The hydrology of salt-affected soils in Australia. D.R. Williamson. *Reclamation and Revegetation Research*, 1986, **5**, 181–96.

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'Report on Salinity in Western Australia.' Select Committee on Salinity. (Western Australian Legislative Council: Perth 1988.)

Salt problems in Perth's hills. *Ecos* No. 4, 1975, 3–12.

Deuterium signatures in a stream

deuterium content (percentage difference from standard water)

