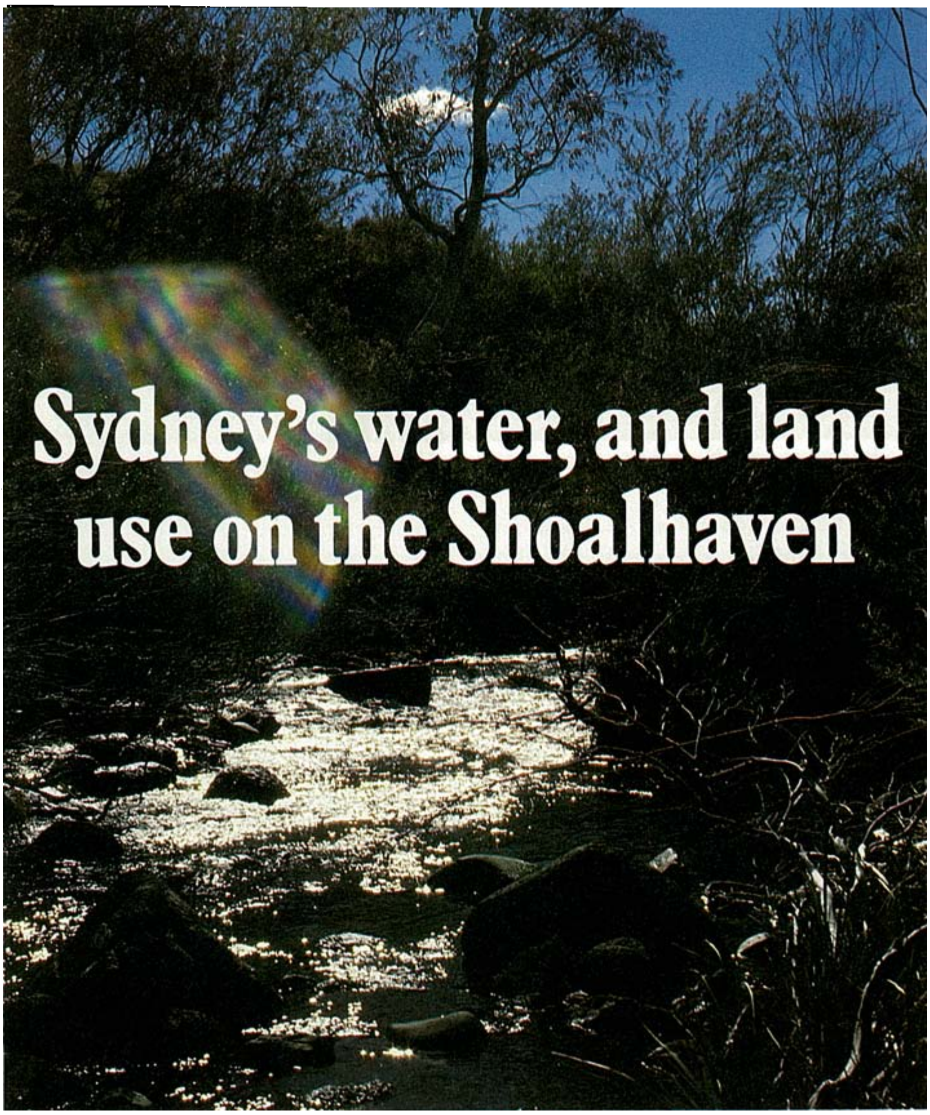
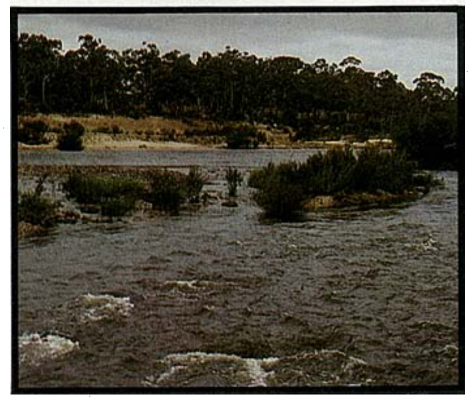
Sydney's water, and land use on the Shoalhaven





Thirsty Sydney is expected to consume 2700 megalitres of water a day by the end of this century, nearly double the present figure and well beyond the supply capabilities of existing headworks.

To meet the demand, the Metropolitan Water Sewerage and Drainage Board has implemented a scheme to bring to Sydney the waters of the Shoalhaven, a river that outflows near Nowra, 160 km away. The headwaters of the Shoalhaven arise in country near Braidwood, east of Canberra. That the water must be pumped uphill is something of a disadvantage; two pumping stations will need to consume sufficient electricity each day to lift 3 million tonnes of water a height of more than 600 metres.

But the Board's carefully planned Shoalhaven scheme turns this feature to advantage. Engineers have designed a reversible system whereby water can be released to flow back downhill through the conduits and generate electricity. In this way, the pumping stations that consume off-peak power can be turned into power stations at times of peak demand. The two pumping stations involved have a combined generating capacity of 400 MW.

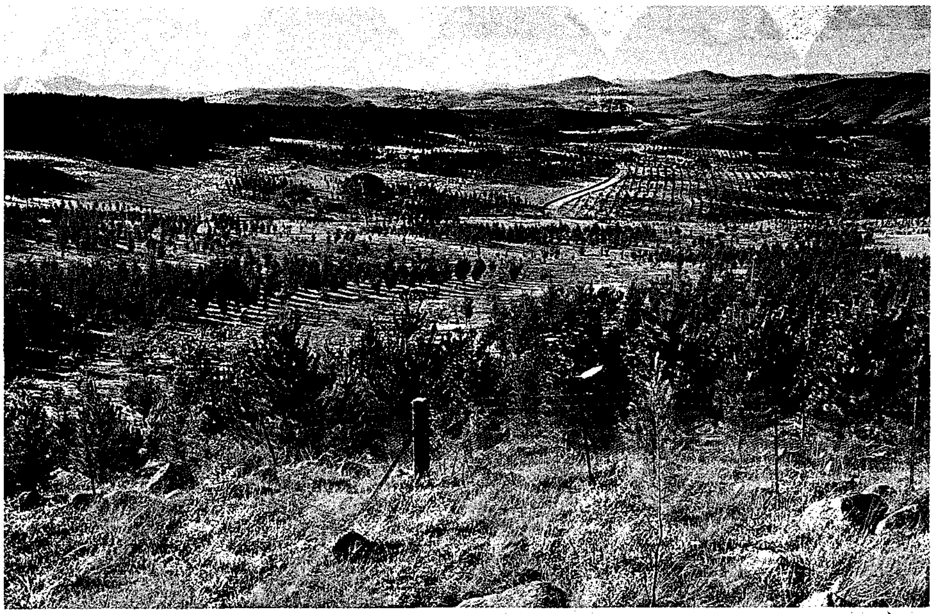
The first stage of the Shoalhaven scheme should be finished next year when the Glenquarry pipeline is installed, allowing water from the Shoalhaven River to reach Sydney for the first time. The other major works in the scheme, estimated to cost $130 million, are described in the box (see page 12). At a later time, a second stage involving the construction of a dam on the upper reaches of the Shoalhaven will be constructed. This Welcome Reef dam will ultimately hold back 2·7 million Ml of water in a lake area of 155 sq km, ensuring that little water escapes impoundment at times of flood and carrying the supply through periods of drought.

When completed, the Shoalhaven scheme should allow nearly the whole flow of the Shoalhaven River at Nowra — 4500 Ml a day — to be harnessed for the use of Sydney and the South Coast. It will nearly double Sydney's water supply.

The run-off into the Shoalhaven is equivalent to about 28% of the annual rainfall over the 7300 sq km of the catchment — a relatively high percentage (more than one-third greater than the average for coastal basins in New South Wales and more than five times the average for the State). In part this is due to the high average rainfall of 900 mm, brought about by a number of high-elevation areas (rainfall in general increases with altitude). The high ground that forms the headwaters of the Kangaroo River in the vicinity of Robertson has an annual mean rainfall of about 1500 mm. Prolonged dry spells are infrequent, although stream flow varies widely here, as it does in most Australian rivers.

So far so good. But what distinguishes the Shoalhaven catchment from most other major urban water supply catchments throughout Australia is that it is not reserved exclusively for its water supply function. In the Shoalhaven we find a wide spectrum of land use. About 30% of the catchment is covered by native pasture, 15% by improved pasture, and the remaining 55% mainly by native timber.

Dairying is the principal agricultural industry in the lower Shoalhaven Valley;



Many pine plantations are springing up on native pasture in the Shoalhaven catchment. These trees use a lot of water, reducing the amount of run-off.

When native pasture, typically kangaroo grass and tussocks (left), is replaced by highly productive grasses and legumes (right), more water is consumed. As a result stream flow is reduced.

of the others, the growing of fodder — such as maize, lucerne, and oats — is the main one. Row and field crops take up about 2% of the total area. Land use in the upper reaches of the Valley is mainly confined to sheep grazing, with some cattle production as well.

Significantly, there is a general trend towards improving native pastures, clearing native forests for the establishment of pine plantations and new pastures, and also converting grazing land to pine plantations. Such changes will obviously alter the amount of run-off, but there is little evidence to tell us by how much. Even though conversion of eucalypt forest to pine forest is widespread in southern Australia, not enough information has been collected to indicate whether the run-off will be increased or decreased. Some suggestive results have been reported in an earlier issue, however ('Forests, grassland, and water catchments', *Ecos 6*).

Land use changes

Dr Alan Aston and Mr Frank Dunin, of the Ecology Section of the CSIRO Division of Plant Industry, have recently completed a 6-year study in the Shoalhaven catchment aimed at finding out the likely consequences of land use changes for stream flow. Their results also indicate changes that could come about in other catchments where pressure for multiple use is mounting.

The main finding is that, if all suitable country was converted from bushland to improved pasture, stream flow would be reduced by 28% in a year of average rainfall.

The pair devised a computer model to arrive at this result. It encompassed two major sub-catchments of the Shoalhaven and enabled the researchers to examine where water went after falling as rain. The main hydrological processes — interception of rainfall by foliage, infiltration into the soil, drainage to the water table, evaporation and transpiration, and surface flow — are all described mathematically. The computer model can evaluate the quantity of water flowing at each 15-minute interval and at each phase of the water's travel.

In other words, the model can calculate the amount of water flowing in a stream simply from the amount of rain falling. This is the first such 'deterministic' hydrological model developed in Australia. All previous models have used stream-flow information from gauging stations to 'optimize' the parameters of a model to accord with different rainfall patterns (see the article on page 29).

Furthermore, the new model has been remarkably accurate; the computed annual stream flow matched the observed annual stream flow to within 10%. This gives confidence that its predictions of flow, when vegetation cover changes are simulated, are reasonably correct.

But of course the price paid for this sophisticated model is a lot of time and effort expended in the field detailing the precise characteristics of soil, vegetation, evaporation rates, and rainfall distribution.

To make the enterprise practicable, Dr Aston and Mr Dunin restricted themselves to the upper Shoalhaven Valley above Welcome Reef. Even so, the two sub-catchments selected for study — the Shoalhaven at Warri and the Mongarlowe at Marlow — have a combined area of nearly 2000 sq km. This area supplies the major storage reservoir in the proposed second stage of the scheme. Furthermore, it is the area where major changes in land use are being undertaken. The combined flow from these two streams produces at least 74% of the flow at Welcome Reef — sometimes up to 90%.

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Lots of data

A network of 11 climate stations was set up around the catchment to supply basic meteorological information — humidity, wind speed, temperature (all needed to calculate evaporation), and rainfall. At each site, data were recorded fortnightly over 2 years. Water balance studies were also undertaken using a neutron moisture meter. This allowed the water-use rates of

Wingecarribee Reservoir, showing the Glenquarry Cut outlet.

A section of the Kangaroo pipeline, with a surge tank visible at the top.

Headwaters of Lake Yarrunga, occupying the Kangaroo River valley.

various vegetation types, such as native grassland, woodland, pine plantation, and so on, to be compared. Soil cores were taken to determine water seepage through them.

Aerial photographs supplied data on vegetation type and also slope. This information was combined with soil type distribution derived from soil maps. Thus, the researchers were able to divide the upper Shoalhaven into small land cells each about 17 hectares. Land cells with the same characteristics were combined to make hydrologic zones. Theoretically, ten rainfall regions, six slopes, five vegetation covers, and seven soil types could yield 2100 combinations. Fortunately for the research pair and the easy running of their model, no more than 150 combinations, or unique hydrologic zones, were obtained in any sub-catchment.

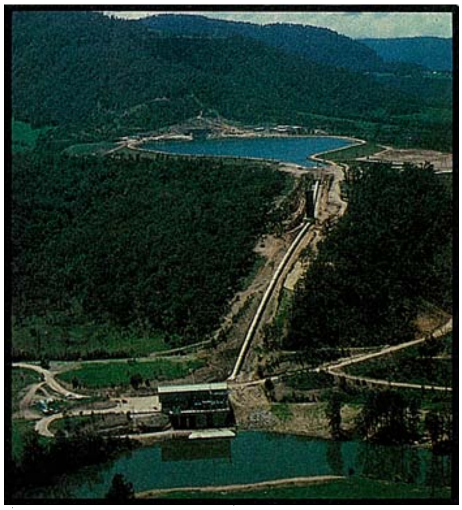
Actually, the researchers did not measure some parameters — such as the resistance of vegetation to overland flow. Instead, they made estimates based on the best knowledge to date. However, these assumptions are unlikely to affect the final result by much. Indeed the largest error is probably due to the assumption that eucalypts and pines do not differ in the way they use water. Most likely they do, but in the absence of any reliable figures, the error, probably small, must remain.

However, the model is designed to calculate the total catchment water yield, rather than the rate of run-off. If the latter (a flood hydrograph) were required, then much more precise data would be required and the model would need modification. The alternative is to use the established empirical methods, where stream flow is extrapolated from measured river heights at known rainfall rates.

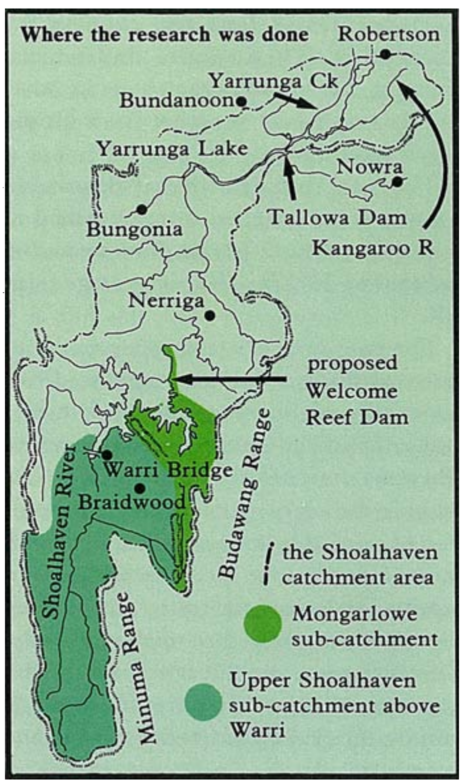
With the present model, if it rains the catchment sheds a quantity of water, and the job of the model is to tell us approximately how much. An important consideration, therefore, is to know how much rain falls over the catchment. For accuracy, the model requires to know the amount of rain that fell in each 15-minute interval. It was not possible to measure this quantity at all hydrologic zones throughout the study area, so the team resorted to the following strategy.

Using annual rainfall figures derived from the existing network of rain gauges throughout the area, the team drew isohyets and assigned a rainfall figure, adjusted for altitude, to sites between these lines. The next step was to use rainfall recorded continuously at Krawaree (within the catchment) from January 1973 to December 1974 as the governing figure for the whole catchment. That is, each site was adjudged to have received the Krawaree rainfall pattern modified by a weighting derived from its annual total.

This technique may be the weakest link in the whole exercise, according to Mr Dunin, but in practice it seems to work well, perhaps because of the nearly overwhelming effect of heavy, protracted storms in contributing to yearly rainfall totals.



Water at the bottom of this picture is lifted across the ridge at the top, a height of more than 600 metres. Starting from Lake Yarrunga, intermediate visible features are: Bendeela Pumping Station, pipeline and surge tank, Bendeela Pondage, and Kangaroo Valley Pumping Station.



The scientists concentrated their efforts on the two sub-catchments shown. These areas contribute up to 90% of the river flow at Welcome Reef, and major changes in land use are occurring there.

Simulated changes

With the model now ready, it could be used for its purpose — as a tool to simulate land use changes. The team 'altered' existing vegetation by introducing a new set of plant parameters and ran the model with the same rainfall data from the 2-year period as before.

They adhered to certain constraints so as to comply with existing land management practices. Only areas with slopes less than 20% were subject to vegetation change. To correspond with Forestry

Commission practice in the Mongarlowe sub-catchment, pine plantations would not be established in areas receiving less than 890 mm average annual rainfall. This constraint was relaxed for the Warri sub-catchment, as commercial plantations have been established on freehold land with lower rainfall.

Dr Aston and Mr Dunin considered extreme examples of the extent of possible change in land use. These were: conversion of native pasture to improved pasture in both sub-catchments, establishment of pine plantations on existing eucalypt forest in the Mongarlowe sub-catchment, and the replacement of both types of pasture with pine plantations in the Warri sub-catchment. Although extreme in extent, these simulations were realistic in the sense that they represented the ultimate projections of existing trends.

The team 'altered' existing vegetation by introducing a new set of plant parameters.

Measuring soil moisture content with a neutron moisture meter.

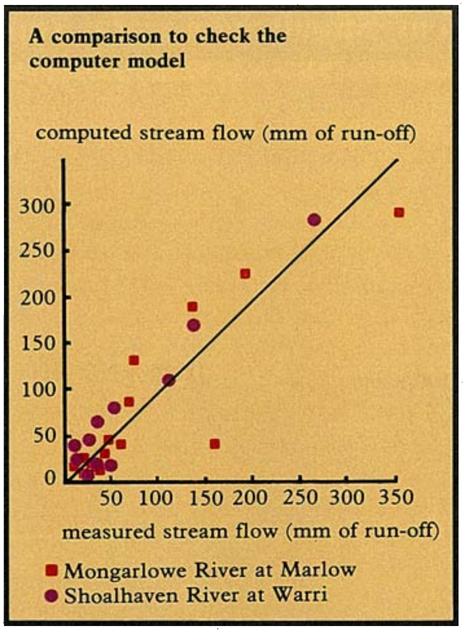
Simulations covered 1973 and 1974, a complete set of data being available for this time. These two years served as a good test for the model in that 1973 was an average-rainfall year while 1974 was an extreme year, with record high annual rainfall in some places and unusually high stream-flow readings.

Results

After the computer had gone through its paces, it showed that the greatest change in stream flow occurred in the Warri sub-catchment, with reductions of 32% (average year) and 26% (wet year) when pasture, covering half the catchment area, was converted to pine plantations. This severe decrease can be attributed to greater evaporation from pines than pasture, both by transpiration and by evaporation from rain-coated foliage.

Looking at the effect of pasture improvement on more than 24% of the Warri sub-catchment and 51% of the Mongarlowe one, the clear result was reductions in stream flow of 24 and 28% respectively, for the average 1973 year. For the wet year, 1974, only minor reductions could be seen. This result reflects the greater consumption of water by exotic species. Native pastures of species like kangaroo grass are practically dormant in winter, leading to little transpiration loss, and their smaller leaf area means less evaporation loss from wet leaves. Improved pasture therefore dries out the soil more, and subsequent rain is thus more inclined to soak in rather than run off.

Taking soil cores for measurement of soil characteristics.



For the two sub-catchments, the measured monthly stream flow is plotted against the stream flow as calculated by the computer model. The points lie fairly close to the line, showing the good performance of the model.

Finally, the model disclosed that conversion of woodland to pine plantations in the Mongarlowe sub-catchment had a negligible effect. This is not to say that the change is hydrologically unimportant. Rather, the lack of discernible effect mainly resulted because, due to the constraints of slope and rainfall, only 3% of the area was altered. Furthermore, because of lack of data, the researchers assumed that the only difference between the water use of pines and eucalypts was the amount of water captured on the foliage and later evaporated. Further research may reveal differences in transpiration as well, as referred to earlier.

Of course, this study overlooked the effect that land use has on water quality. But it has demonstrated that the quantity of water available for storage and consumption can be affected greatly by land use decisions. Although the work to date has only covered years of average and plentiful rainfall, Mr Dunin would guess, on the basis of results so far, that in a dry year the replacement of pasture by pines could make all the difference between some water and none.

Andrew Bell

More about the topic

Shoalhaven land use hydrology. A. R. Aston. *CSIRO Division of Plant Industry Annual Report*, 1977, 21–7.

Shoalhaven land use hydrology. A. R. Aston and F. X. Dunin. *Journal of Hydrology*, 1980 (in press).

The Shoalhaven water supply scheme

The fundamental idea of the scheme is to take water from a dam on the Shoalhaven River and to pump it via a series of pumping stations, reservoirs, and canals to Wingecarribee Reservoir, 800 m above its starting point. The water can also be released to flow back down and generate peak-demand electricity.

From the Wingecarribee Reservoir, water can be released into the Wingecarribee River, whence it will flow into the Wollondilly River and thus into Lake Burragorang for supply to Sydney. Water from Wingecarribee can also be released via the Glenquarry cut and pipeline to flow into Nepean Reservoir for areas served by that system, which includes the South Coast (through the Nepean–Avon tunnel).

Sydney will be ready to receive water from the scheme in July 1980, when the Glenquarry pipeline is scheduled for completion.

The major works in the scheme are:

TALLOWA DAM — a concrete gravity structure 43 m high and 520 m long immediately downstream of the junction of the Shoalhaven and Kangaroo Rivers. The dam can hold 85 500 Ml (creating the 8-sq-km Lake Yarrunga), of which 36 000 Ml can be pumped out.

TWO PUMPING/POWER STATIONS. Bendeela station, on the Kangaroo River arm of Lake Yarrunga, lifts water 127 m to a 920-Ml balance reservoir, Bendeela Pondage. At the foot of an escarpment, Kangaroo Valley station raises water from the pondage another 500 m through tunnel, pipeline, and canal to Fitzroy Falls Reservoir.

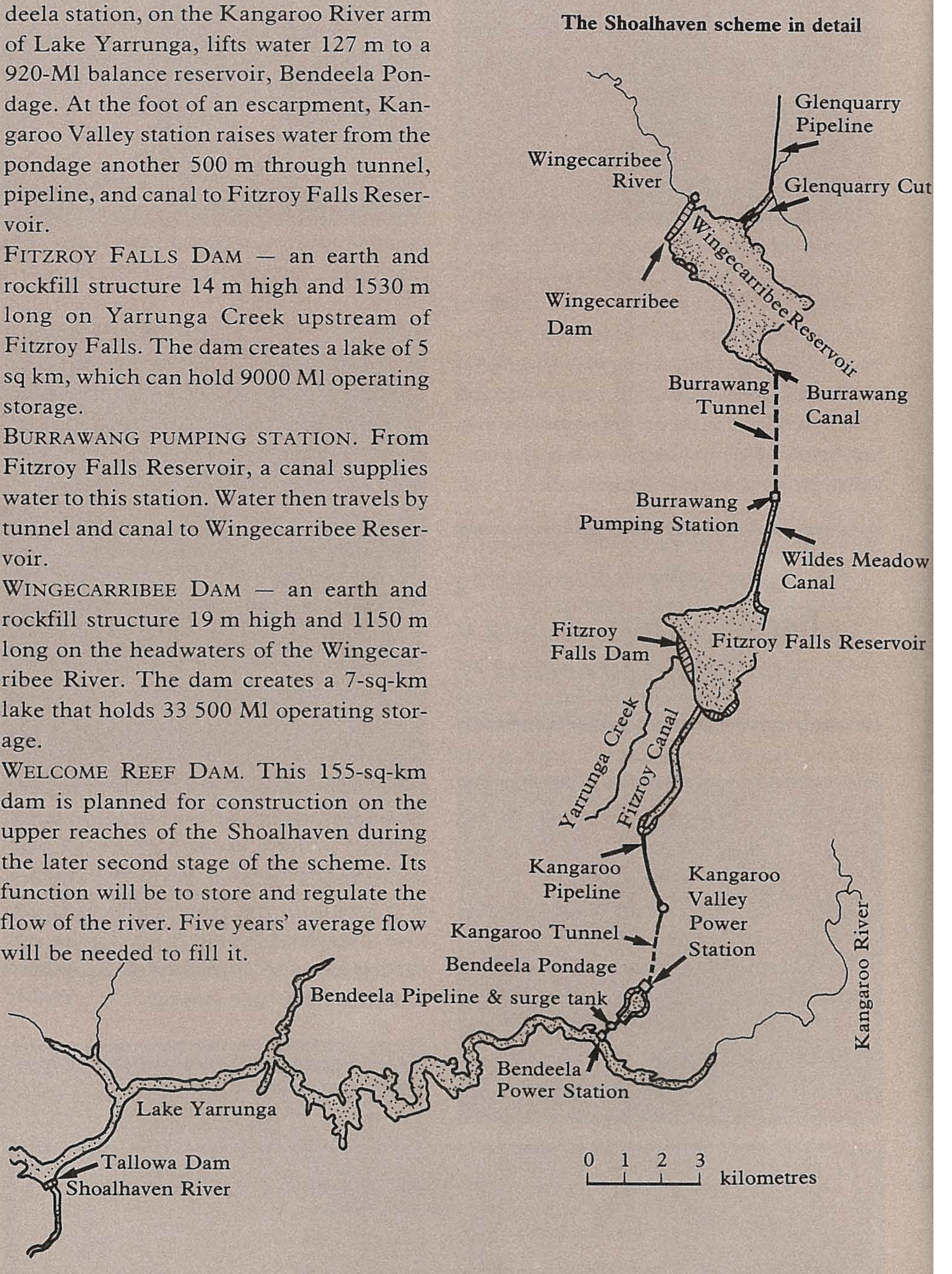
FITZROY FALLS DAM — an earth and rockfill structure 14 m high and 1530 m long on Yarrunga Creek upstream of Fitzroy Falls. The dam creates a lake of 5 sq km, which can hold 9000 Ml operating storage.

BURRAWANG PUMPING STATION. From Fitzroy Falls Reservoir, a canal supplies water to this station. Water then travels by tunnel and canal to Wingecarribee Reservoir.

WINGECARRIBEE DAM — an earth and rockfill structure 19 m high and 1150 m long on the headwaters of the Wingecarribee River. The dam creates a 7-sq-km lake that holds 33 500 Ml operating storage.

WELCOME REEF DAM. This 155-sq-km dam is planned for construction on the upper reaches of the Shoalhaven during the later second stage of the scheme. Its function will be to store and regulate the flow of the river. Five years' average flow will be needed to fill it.

The main elements in the first stage of the Shoalhaven scheme are shown here. In the second stage the major feature is the large Welcome Reef dam (shown on the other map).



The elements of the Shoalhaven scheme in profile. Water rises more than 600 metres.