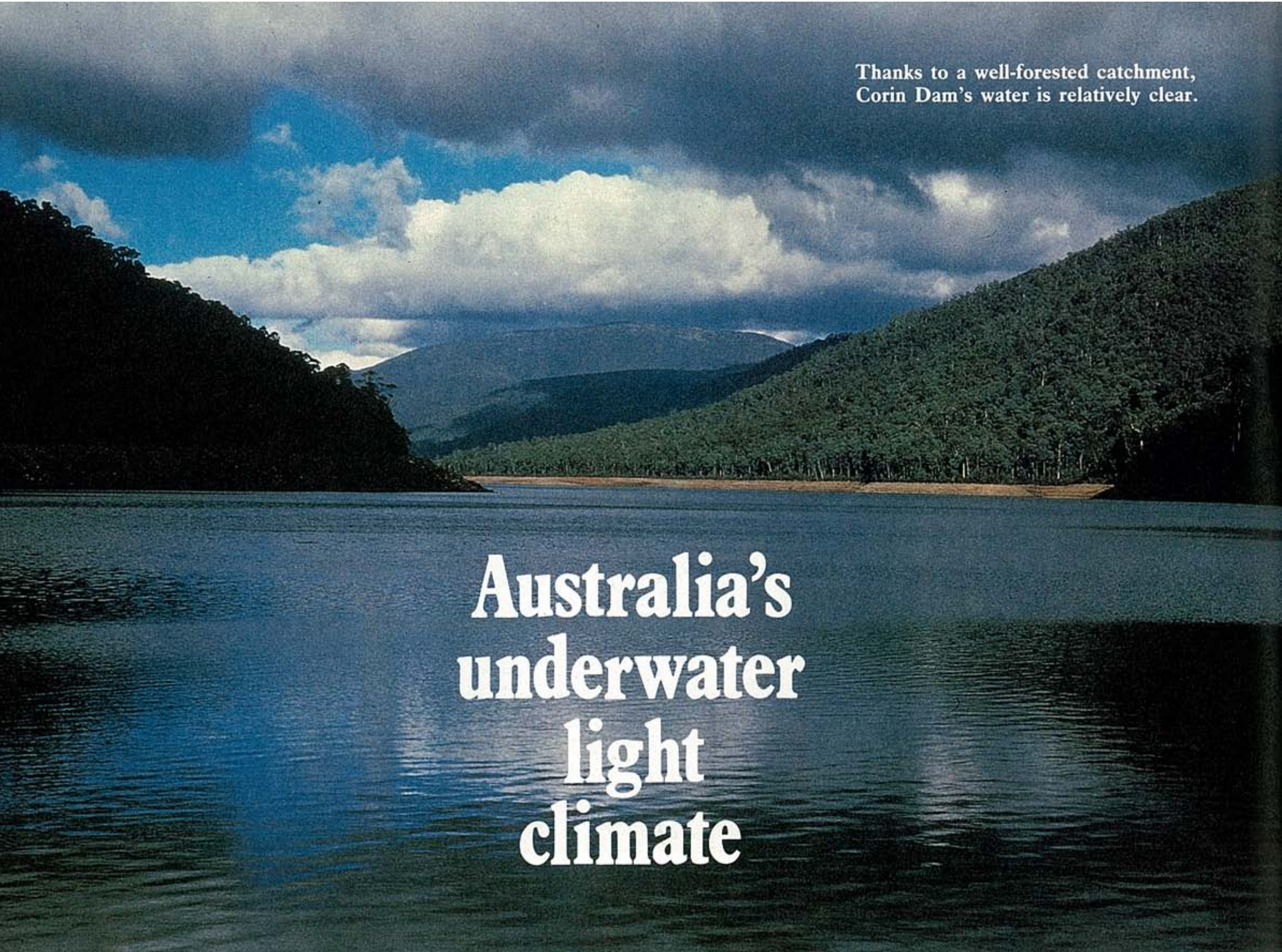


Thanks to a well-forested catchment, Corin Dam's water is relatively clear.

Australia's underwater light climate

Australia's native flora and fauna have taken some hard knocks over the last couple of hundred years, but some species flourish in congenial conditions created by European man. The lucky winners include aquatic plants.

Originally restricted to natural lakes and rivers, fresh-water 'weeds' and algae — their variety augmented by introduced species from overseas — now abound in reservoirs, farm dams, irrigation channels, and ornamental ponds. Sometimes their success threatens man's: irrigation water cannot flow efficiently along choked canals, and an algal bloom in a metropolitan reservoir soon has citizens telephoning their complaints that the tap water 'tastes bad'.

Even if it were practicable to kill all the plants in conflict with man, that idea holds little appeal. Dead bodies of water would be as unattractive for recreation as the 'green soups' we periodically experience now, and wildlife would suffer a severe setback.

The answer is to manage these fresh-water ecosystems, much as we manage farmland, parks, and plantations. Armed with a thorough understanding of the physical, chemical, and biological processes going on in water, we may be able to adjust the conditions in irrigation ditches and reservoirs in a way that restricts the growth of unwanted plants. And where we cannot do that, we should at least be able to assess what management options do stand a chance of being effective.

A good understanding of fresh-water ecosystems should also enable us to predict, and where necessary forestall, the impact on aquatic plants of industrial and other developments.

Unfortunately we lack that thorough understanding, which is why Dr John Kirk resolved in 1973 to investigate the factors influencing the growth of water plants.

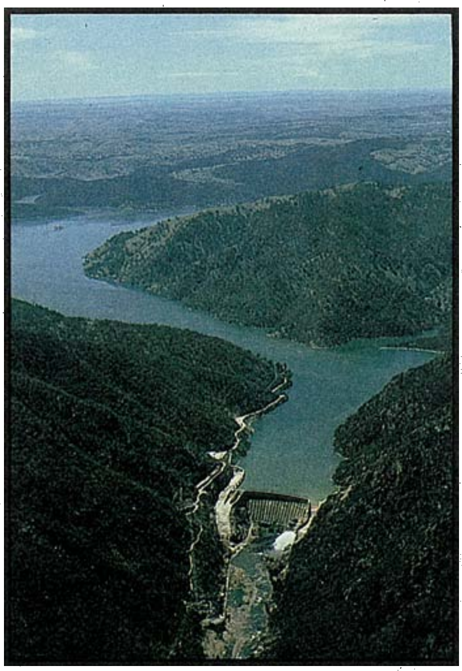
Green plants add to their substance by photosynthesis, and the rate at which photosynthesis proceeds under water depends mainly upon how much light is available. Certain nutrients may be in short supply, but Australian waters are so murky that light is generally the limiting factor. Limnology textbooks describe the limpid lakes and tarns of northern Europe and the northern United States of America, and Dr Kirk had to pioneer the study of light penetration through cloudy waters of the kind so common on this continent.

What gives Australian creeks and lakes their characteristic turbidity and yellow-brown colour, anyway?

Nobody knows for certain, but Dr Kirk suspects soil erosion is the main cause. Lakes with well-forested catchments contain clearer water than those draining grazing land. It would be interesting to compare our modern waters with those of 200 years ago, but of course no suitable measurements were made then; indeed, many of our inland lakes, being man-made, did not exist at that time.

Useful wavelengths

Dr Kirk began by investigating the 'light climate' in a number of bodies of water. The spectrum of light that plants use for



Burrinjuck Dam during an algal bloom.

photosynthesis more or less coincides with the range of wavelengths that our eyes detect as visible light, but not all wavelengths are equally 'useful' to a plant.

Chlorophyll looks green because it does not absorb wavelengths in the green part of the spectrum. In photosynthesis, most plants make best use of the light in the red and blue regions of the spectrum, because these are the wavelengths that chlorophyll and carotenoids absorb. However, water itself, which is intrinsically blue, absorbs red wavelengths; and so, with increasing depth, submerged plants depend more and more on blue light.

Australian waters are so murky that light is generally the factor limiting plant growth.

Dr Kirk, assisted by another member of the Division, Mr Clive Hurlstone, lowered a special instrument into several lakes to find out how much light was penetrating to different depths. The instrument, a quanta meter, measures the amount of radiation in the 'photosynthetic band' — wavelengths in approximately the range 400–700 nm (nanometres); 1 nm is a thousand-millionth of a metre.

We particularly need to know man's impact on the light climate, so Dr Kirk concentrated on lakes used a great deal

A closer view of the phytoplankton-rich water of Burrinjuck Dam.

Lake George is so shallow that a light wind stirs up sediment and clouds the water.

Lake George's murky water.

Advanced technology for underwater light measurement is more commonly used here than in countries with longer limnological traditions.

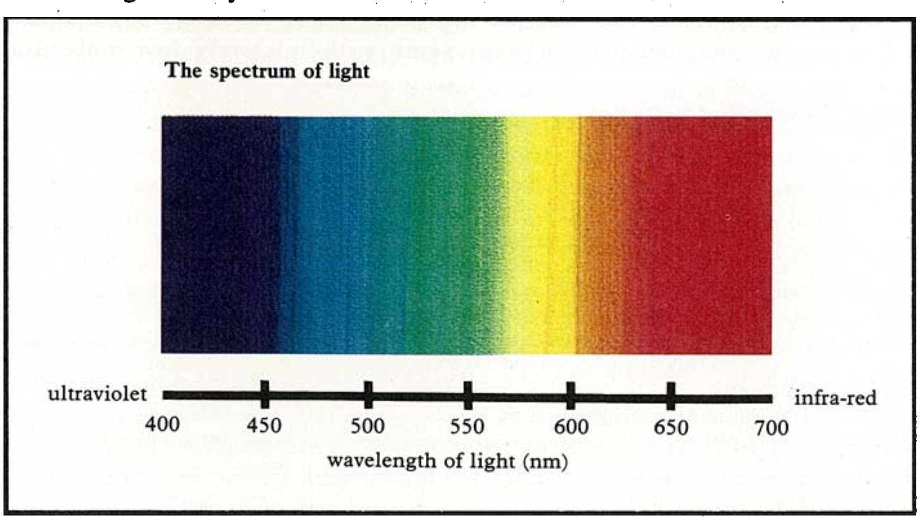
for recreation and other purposes, comparing them with the open sea and an estuary. These measurements are still being made, providing an increasingly detailed picture of the seasonal changes and annual fluctuations in inland waters.

Dr Kirk and Mr Hurlstone have also used a more sophisticated instrument, a spectro-radiometer, to determine how much light of each colour reaches plants at various depths below the surface. Prompted by these studies, other Australian limnologists are now routinely using submersible quanta meters and spectro-radiometers; indeed, these advanced technologies for underwater light measurements are more commonly used in Australia than in countries with much longer limnological traditions.

A photon's fate

Dr Kirk then tackled the question of what gives rise to the particular light climates that he found. To understand the processes at work, let us follow a photon (one quantum of light energy) into the water.

The ultimate fate of a photon is to be absorbed by something that it hits. Our photon may surrender its energy to a molecule of chlorophyll in a plant, and so help to drive the energy-demanding synthesis of carbohydrates.



Alternatively it may be absorbed — for example, by the water itself, by a dissolved substance or a suspended particle in the water, or by the bed of the lake. The deeper the water, therefore, and the more matter it holds in solution or suspension, the less chance our photon has of reaching the bottom. Naturally, a bookmaker would quote different odds for different wavelengths of light.

Our photon is not necessarily absorbed by the first thing it bumps into; it stands a good chance of ricocheting one or more times. After all, if light did not reflect off objects, we should not see them. Some photons may even rebound through the surface of the water into the atmosphere, but many more are deflected through only small angles.

The turbid waters so characteristic of inland Australia hold particularly large numbers of particles, which not only absorb some light that would otherwise travel deeper but also deflect photons, causing them to spend longer in the surface layers and therefore increasing their likelihood of being absorbed somewhere in those layers.

What absorbs light?

Apart from water, what else absorbs light in our lakes and rivers?

One important category of substances is a group of dissolved yellow pigments collectively known in the past as 'yellow substance' or (the German equivalent) 'Gelbstoff'. As Dr Kirk has pointed out, the name 'yellow substance' could refer to 'anything from butter to ferric chloride'; he has therefore proposed for these pigments a specific term 'gilvin', from the Latin word *gilvus*, meaning pale yellow.

Gilvin apparently occurs universally in inland waters, but most Australian lakes contain so much gilvin that it absorbs even more light than does water. Being yellow, gilvin removes mainly blue wavelengths from light, and thus presents a serious environmental handicap to submerged plants, which are already starved of red wavelengths by the water itself.

A corner of Lake Burley Griffin rich in tripton.

Much Australian water looks yellow. The colour comes partly from the gilvin, which forms a clear solution, and partly from a variety of suspended particles, comprising mostly tiny fragments of decomposed plant material and soil. This fraction, called tripton, both scatters and absorbs light.

Measuring tripton's absorption spectrum (the quantities of light of different colours that it absorbs) presents far greater challenges than carrying out this procedure on a solution, and Dr Kirk had to develop a technique specially for the purpose. This enabled him to quantify tripton's contribution to the underwater absorption of light, something that had never been done before.

Where the colour comes from

The precise origin of the colours of both gilvin and tripton remains a mystery, but they probably derive from the partial decay of plant material in soil. Humus, the rich, brown organic fraction in soil, contains an enormous number of chemicals; some with relatively low molecular weights dissolve in water and probably contribute to gilvin, and others with larger molecules fail to dissolve and therefore join the tripton when erosion carries soil into the waterway.

Because the absorption spectra of gilvin and tripton match one another closely, showing little absorption of red wavelengths and increasing absorption towards the blue end of the photosynthetic band, Dr Kirk believes that the coloured components in tripton must, like gilvin, derive mainly from humic matter in soil.

Some of the colour in gilvin and tripton may well come from the decomposition of plants that grew in the water. These include not only conspicuous macrophytes, the 'water weeds', but also microscopic algae that become apparent to our eyes only when a population explosion of one or other of them creates a bloom visible kilometres away.

Prolonged dry weather, heavy rain, or an algal bloom can switch some lakes from one light-absorbing category to another.

During a bloom, the phytoplankton population may absorb enough light to restrict its own growth, but usually the light climate is determined less by algae than by water, gilvin, and tripton.

In order to separate the respective optical roles played by these different fractions, Dr Kirk filtered his lake samples. He already knew what contribution water made; that never changes. By comparing

Inland waters studied by Dr Kirk

	catchment	use by man
Corin Dam, A.C.T.	native eucalypt forest	Canberra's water supply
Lake Ginninderra, A.C.T.	urban, cleared pasture	ornamental, recreation
Googong Dam, N.S.W.	pasture, native forest	Canberra's water supply
Cotter Dam, A.C.T.	native forest, pine plantations	Canberra's water supply
Burrinjuck Dam, N.S.W.	cleared pasture, native forest	storage for Murrumbidgee Irrigation Area
Lake Burley Griffin, A.C.T.	cleared pasture, native forest, urban	ornamental, recreation
Lake George, N.S.W.	cleared pasture, native forest	none (natural impermanent lake)

his filtrate with pure water he determined gilvin's optical properties, and by washing the filter he obtained the particulate fraction for analysis.

This procedure does not separate tripton from phytoplankton, but Dr Kirk formed a good idea of the respective optical influences of these two fractions by examining samples from lakes containing high ratios of algae to tripton and *vice versa*.

By carrying out, with the help of a computer, separate calculations for each 10-nm-broad waveband throughout the photosynthetic spectrum, Dr Kirk was able to determine the relative contributions that the different components of the water body made to the absorption of photosynthetically active light.

In addition to his own samples, he has examined some from other scientists: Dr Peter Tyler of the University of Tasmania, who is studying billabongs that may be affected by the Ranger uranium project in the Northern Territory; Dr David Mitchell of the CSIRO Division of Irrigation Research, who is examining canals in the Murrumbidgee Irrigation Area; and the Marine Studies Group of the Victorian Ministry for Conservation, which is conducting a survey of the Gippsland Lakes.

The ultimate fate of a photon is to be absorbed by something it hits.

How light is absorbed

lake	date	percentage of light absorbed by water	by gilvin	by tripton and algae
Corin Dam	8 June 79	34·8	60·0	5·2
Lake Ginninderra	6 June 79	39·1	50·4	10·5
Googong Dam	21 June 79	22·0	60·4	17·6
Cotter Dam	8 June 79	26·2	49·8	24·0
Burrinjuck Dam	7 June 79	28·2	45·5	26·3
Lake Burley Griffin	6 June 79	19·4	22·2	58·4
Lake George	28 Nov. 79	12·4	8·3	79·3

Types of lakes

From a comparison of all his results, Dr Kirk has concluded that Australian lakes fall into a small number of categories. In one, which he calls type G, with clear, yellow water, gilvin plays the dominant role in light absorption.

Type GA waters contain more phytoplankton; in these lakes gilvin is more effective than other components at absorbing the shorter wavelengths (the blue end of the spectrum), but algae dominate the absorption of red light. In more turbid water — type T — rich in tripton, the particulate fraction absorbs more light than gilvin does throughout the spectrum.

Dr Kirk has not yet found an Australian type W lake — so clear of algae and silt that its pattern of light absorption is dominated by water itself. His only example of this type of water has come from the open sea off Bateman's Bay.

A lake's category is largely determined by its catchment area. Water runs into Corin Dam in the Australian Capital Territory from native eucalypt forest, and the lake is clear and brown, showing the characteristics of type G. By contrast, soil erodes readily off cleared agricultural land like that in the catchment of Lake Burley Griffin (Canberra); this water therefore belongs to type T for much of the time.

Prolonged dry weather, heavy rain, or an algal bloom can switch some lakes from one category to another.

Other categories exist. For example, in those Northern Territory billabong waters that Dr Kirk has examined, gilvin and tripton absorb roughly equal amounts of light throughout the photosynthetic spectrum, and the billabongs may be designated type GT. However, the lakes he has studied in the Southern Tablelands all seem to belong to the three classes, G, GA, and T.

New angles

So far we have looked mainly at absorption; what about light-scattering? This is harder to measure.

Physicists recognize two distinct properties, both of which must be quantified. One is the scattering coefficient, a measure of the total scattering of light; the other, called the volume scattering function, is a measure of the extent to which photons are deflected through various angles from their original path.

In the past, scientists needing absolute measurements of these two properties have built equipment specially for the purpose — a major undertaking. Dr Kirk therefore made a theoretical study of light scattering, and found that he could arrive at good estimates of the scattering coefficient using the field measurements now being routinely made in Australian waters.

In this way he has not only dodged the problem of constructing elaborate apparatus, but also made it possible to calculate the scattering coefficient in any lake for which standard underwater light measurements have been made, no matter how long ago.

Eventually he would like to obtain absolute values for the scattering coefficient, in order to check the accuracy of his theoretical estimates, but meanwhile he is confident of their usefulness. They certainly correlate well with measurements of turbidity made using the usual technique, which involves comparing a water sample against particulate suspensions of standard murkiness.

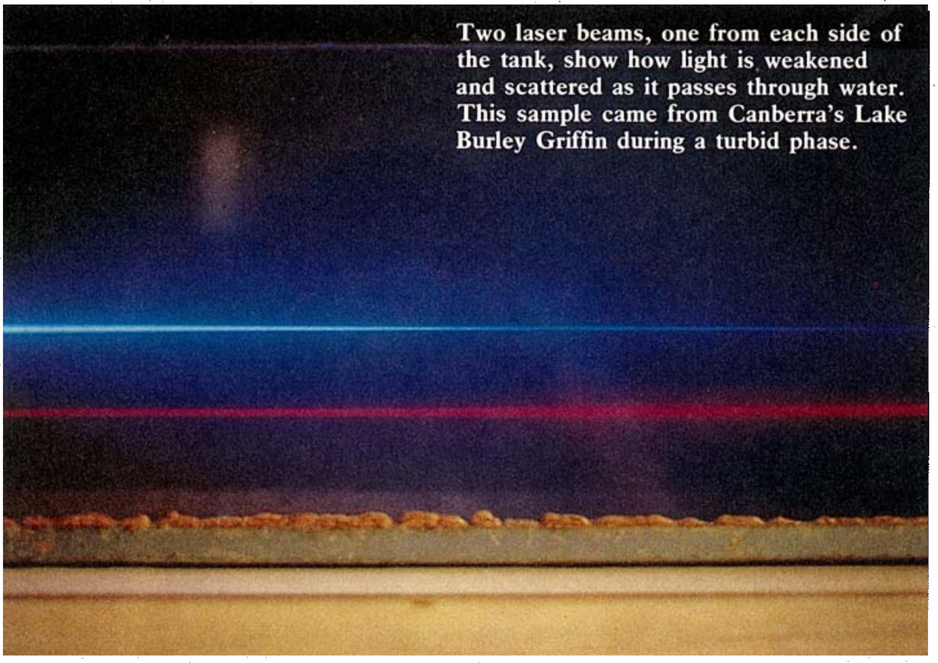
The other light-scattering property, the volume scattering function, is a particularly tough experimental nut to crack, and few measurements of this function have been made anywhere in the world.

Suppose that somebody plans to build a paper mill beside a river. Will aquatic plants be affected?

When a beam of sunlight passes through a thin layer of water, only a small proportion of the photons are deflected, most of them through only a small angle, so the scientist is trying to measure faint beams at small angles to the bright main beam. In his theoretical studies Dr Kirk has used published values for the turbid water of San Diego Harbour, California.

Building a model

And so, by measurement, estimation, and computation, Dr Kirk put together a picture of the underwater light climate in the inland lakes of south-eastern Aus-



Two laser beams, one from each side of the tank, show how light is weakened and scattered as it passes through water. This sample came from Canberra's Lake Burley Griffin during a turbid phase.

tralia: not only what it is like but why it is that way. Equipped with this knowledge, he then developed a mathematical model that will enable people to predict the effect on underwater light, and therefore on plant growth, of changes in the water.

Suppose that somebody proposes to build a paper mill beside a river. We know the mill's effluent will be coloured by substances extracted from wood during paper-making; the effluent will, in fact, be something like gilvin. Will aquatic plants be affected?

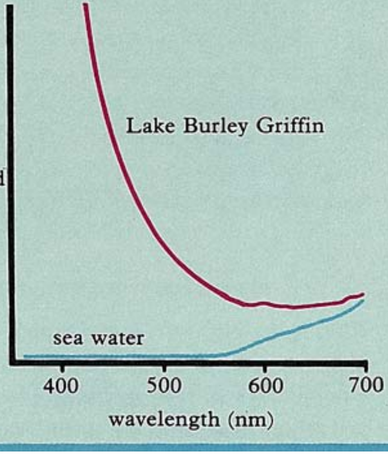
Thanks to Dr Kirk's model it should now be possible to answer that question. All we need to know is the optical properties of the effluent.

To use the model, we must program a computer to 'consider' what happens to a photon as it passes through the water. Since the photon's fate is not certain, but determined by a number of risks of different probabilities, the computer has to 'decide' how far the photon travels before colliding with something, whether it is then absorbed or deflected, and if deflected through what angle, and so on.

The computer arrives at each 'decision' with the help of figures supplied by its programmer, including values for the optical properties of the water being studied, and random numbers generated to provide the chance element. In a way the whole exercise resembles roulette, which is why this type of operation is called a Monte Carlo study.

Eventually the postulated photon may be absorbed by something in the water, such as gilvin or an algal cell, it may hit the bed of the lake, or it may even return to the atmosphere.

No single photon whose course and ultimate fate are 'charted' in this way can possibly be 'typical', but after following the paths of about a million photons, one at a time, the computer produces a reasonably complete and reliable picture of the light field that will be set up in the body of water, real or hypothetical, that is under investigation.



Murky water absorbs light

Pure water, here exemplified by sea water, absorbs red light. The yellow solutions and particles in Australian lakes absorb much blue light as well.

Missing link

Does Dr Kirk's mathematical expression of light's underwater behaviour give the right results? To find out, he instructed a computer to carry out a Monte Carlo study on each of four New South Wales lakes, and he then put the computer's predictions beside light measurements made in the lakes themselves. The computer's results agreed well with the field values.

Plant physiologists know a good deal about the influence of different types and amounts of light on photosynthesis, so computer calculations of this kind could be used to predict changes in underwater primary production — that is to forecast whether plant growth will be affected by new conditions in the water.

The one missing link in the computational chain is the connection between, on the one hand, a proposed change in land use and, on the other hand, new values for the optical properties of affected water.

Before we can assess the likely effect of a riverside factory on the river's ecosystem, we must know the absorption spectrum and light-scattering properties of that factory's effluent. Likewise, to predict the consequences to aquatic plants of clear-felling a catchment hillside, or of revegetating land, we need to quantify the relation between different types of plant cover and soil erosion.

In short, we need to know how different kinds of land use affect the optical properties of nearby lakes and dams, and Dr Kirk regards this as the next challenge in his study. Given such information, he believes that we shall be able to assess the environmental impact on inland waters of proposed developments far more satisfactorily than has previously been possible.

John Seymour

More about the topic

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Light in murky waters. *Ecos* No. 13, 1977, 22–5.