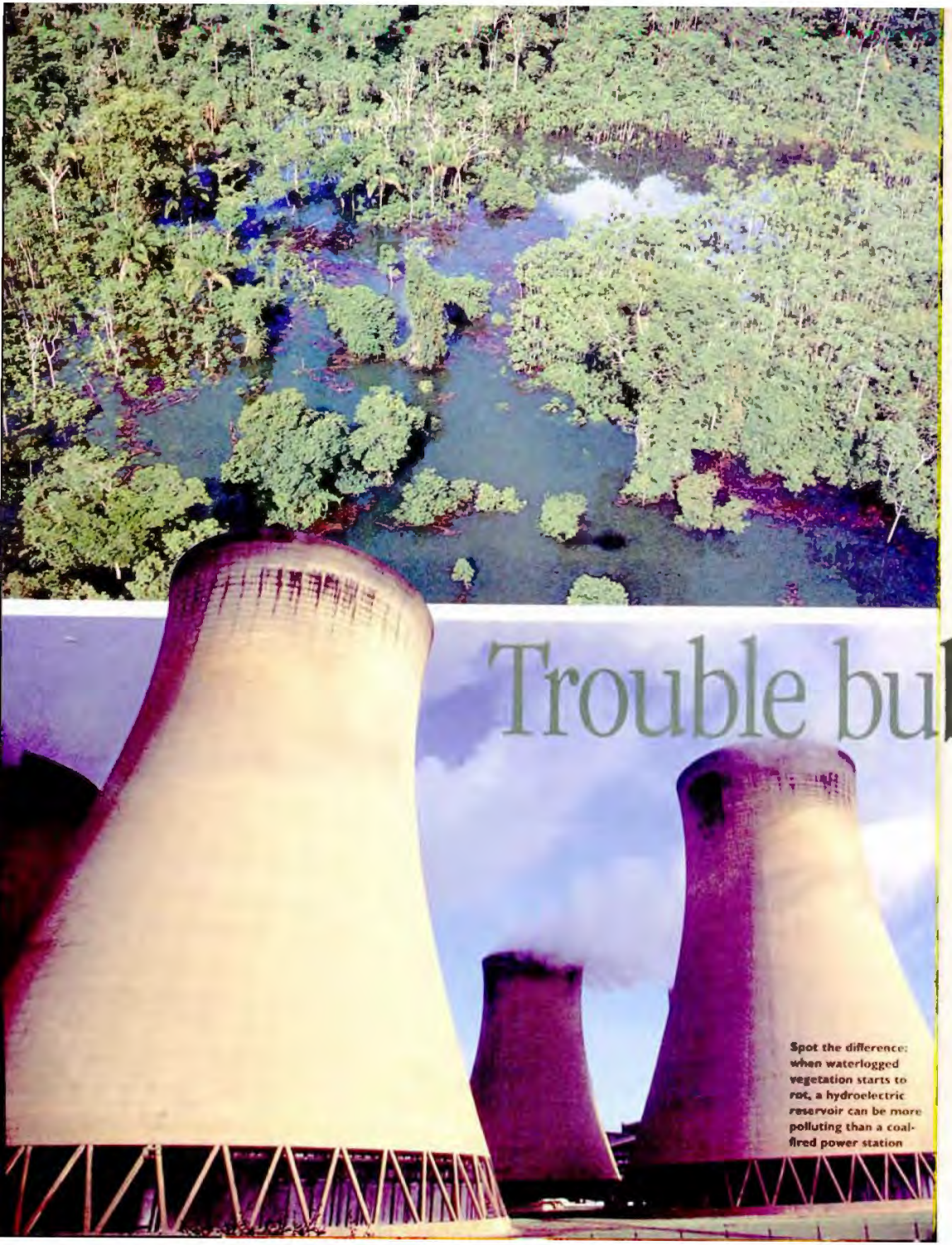

Planet Earth

Spot the difference: when waterlogged vegetation starts to rot, a hydroelectric reservoir can be more polluting than a coal-fired power station

EcoScene/Corbis

Trouble bubbles for hydropower

From China to Norway, new hydroelectric schemes are supposed to help cut emissions of greenhouse gases. But will they? *Fred Pearce* investigates

SHIMMERING waters in remote mountain reservoirs providing hydroelectricity seem a world away from the grimy coal-burning power stations of industrial landscapes. Hydroelectric plants burn nothing and apparently cause no air pollution—no acid rain, no grimy particles. They are, surely, the ultimate clean sources of energy. Most countries categorise hydropower as a "zero-emission technology". And governments around the world are committed to cutting their future output of greenhouse gases by building hydroelectric dams instead of fossil-fuel power stations.

But their efforts may be misguided. Studies on reservoirs from the Canadian Arctic and the jungles of the Brazilian Amazon are starting to show something odd. Many of these large bodies of water—in effect pent-up energy waiting to pour through turbines—themselves produce greenhouse gases. They give off large amounts of both carbon dioxide and methane, which accumulate in the atmosphere, trapping solar heat and so contributing to the greenhouse effect. As a result some reservoirs cause more global warming than coal- or oil-fired power stations producing the same amount of energy.

One of the worst offenders is the Balbina reservoir on the River Uatumã, a tributary of the Amazon deep in the Brazilian rainforest. The dam supplies most of the electricity for Manaus, the capital of the Amazon region. It is a modest 50 metres high but floods 310 000 hectares of river valley, an area the size of Lancashire or Luxembourg. From the air, the great expanse of water looks more like a temporary flood than a permanent reservoir. A third of the water is less than 4 metres deep and the skeletons of dead and dying trees break the surface almost everywhere. Water flow is sluggish and much of the reservoir is stagnant and covered in weeds.

In common with many other dam builders, the engineers who built the Balbina dam in the mid-1980s made no effort to remove the trees before flooding the site. With no accessible market for the timber, felling was not economically viable, so the reservoir was allowed to inundate more than 100 million tonnes of vegetation. As it decays most of the carbon it contains will eventually be released into the air.

Reservoir bogs

Philip Fearnside, an ecologist at Brazil's National Research Institute for Amazonia, has studied the gases emitted from the reservoir. Decaying plants breaking the surface water produce CO_2, as does rotting vegetation in the oxygenated waters within a metre or so of the surface. But vegetation in the anaerobic waters produces methane. In shallow areas of the Balbina reservoir, says Fearnside, "methane bubbling can be seen everywhere". And more is lurking in the depths. It is sometimes released suddenly, as happened in 1993 at Balbina, killing thousands of fish. Otherwise, it may leak into the atmosphere as water passes through the turbines.

Fearnside calculates that in the nine years since the Balbina reservoir formed behind its dam, there has been a dramatic release of CO_2. In 1988, the first year after flooding, the reservoir emitted more than 10 million tonnes. Today, the annual figure has fallen to about a quarter of that. Methane is produced much more slowly. In the first year, some 150 000 tonnes emerged from the reservoir. But that figure will be maintained more or less indefinitely. In the Amazon, says Fearnside, it takes 500 years for a tree trunk to decay in anoxic water.

Assessing the damage resulting from the release of CO_2 and methane is complicated. CO_2 persists much longer in the atmosphere—an average molecule will stick around for a century, compared to a decade or so for methane. But while it is there, methane is a much more potent greenhouse gas. So what time frame should be used for any damage assessment? Fearnside adopts a formula from the UN's Intergovernmental Panel on Climate Change that, for the first century after its release, a molecule of methane will have 11 times as powerful a greenhouse effect as a molecule of CO_2. A longer time frame produces a lower figure. A shorter period produces a higher figure. Over the first 20 years, for instance, methane is 60 times as potent.

However the sums are done, it is clear that any increase in the amount of vegetation rotting to methane rather than CO_2 will have a major influence on the greenhouse effect of a reservoir. Flooded forests are often major sources of methane and none more so than those of the Amazon basin. Here, says Fearnside, "the environment, devoid of oxygen, with relatively high temperatures and high levels of nutrients, makes it ideal for methane-producing decay processes". Even without artificial flooding, the Amazon is "one of the world's major sources of methane", says Fearnside. About 2 per cent of the Amazon region—around 100 000 square kilometres—floods for part of each year. And reservoirs add significantly to the region's natural propensity to generate methane.

Dam pollution

At Balbina, Fearnside has aggregated the greenhouse effect of methane and CO_2 to give a "CO_2 equivalent", that he can compare directly with emissions from fossil-fuel power stations. He calculates that Balbina emitted the equivalent of more than 12 million tonnes of CO_2 in its first year. That figure fell to some 7 million tonnes in 1990 and to around 2 million tonnes last year. It will slip below 1 million tonnes in about 10 years' time, and drop to 0·5 million tonnes in perhaps 50 years.

How do these figures compare with conventional power stations? Balbina's average output of electricity in the first eight years of its operation was

South American Pictures

Swimming trunks: flooded Amazonian rainforest readily decays to methane

112 megawatts—not much for a reservoir the size of an English county. It floods the equivalent of two soccer pitches to generate enough power to run a 1-kilowatt electric fire.

If the Balbina dam had not been built, the authorities in Manaus would probably have constructed a conventional power station burning diesel and fuel oil. Such a plant would have produced annual emissions—almost all of it carbon dioxide—of some 0·4 million tonnes, says Fearnside. So far, Balbina has had something like 16 times as potent a greenhouse effect as an equivalent fossil-fuel power station. And, says Fearnside, despite gradually reduced emissions, it will continue to be more polluting "for 50 years, and probably indefinitely".

Fearnside has looked at other reservoirs in Brazil. None is as bad as Balbina but emissions are far from negligible. Take the giant Tucuruí dam on the River Tocantins. Completed in 1984, it is one of the world's ten most powerful hydroelectric dams, with a capacity of 4000 megawatts. It flooded a little less forest than Balbina, but generates more than 30 times as much power. Even so, after six years of operation, it was still emitting the equivalent of almost 3 million tonnes of CO_2 per annum. This is almost half as much as a fossil-fuel power station of a similar capacity, says Fearnside. He estimates that in 1990, Brazil's four rainforest reservoirs were producing the equivalent of some 11 million tonnes of CO_2 annually.

Trends in the North

It is hard to imagine two environments more different than the Amazon rainforest and the Canadian Arctic. Yet here too researchers have found high emissions of greenhouse gases from reservoirs. Canada has hydroelectric reservoirs covering about 20 000 square kilometres, an area nearly the size of Wales. They produce around 60 per cent of the country's electricity.

Three years ago, John Rudd and his colleagues at the Canadian government's Freshwater Research Institute in Winnipeg investigated several hydroelectric sites to produce the first detailed calculations of gas production from reservoirs. Rudd concluded that upland forests and peat bogs—the two main habitats flooded for reservoirs in Canada—"are sites of intense microbial decomposition and greenhouse gas production when they become covered in water".

At the Notigi reservoir in northern Manitoba, Rudd found that two years after the flooding of a forest there were massive amounts of methane dissolved in the surface layers of the lake. He estimated that annual production at that time was more than 7 grams of methane for every square metre of the reservoir's surface. In a second study Rudd's team looked at methane and CO_2 emissions from flooded peat bogs. They found still higher gas production—up to 30 grams of methane and between 450 and 1800 grams of CO_2 per square metre.

Rudd calculated the likely impact of these gases on the atmosphere during the expected 50-year productive lifetime of a hydroelectric reservoir. He estimated that two-thirds of the vegetation and soil flooded by new reservoirs would decay over that period, but much less of the woody material. And that up to a tenth of the carbon in the vegetation would be released as methane, with the rest forming CO_2. Averaged over the 50 years, he says, each square metre of a typical reservoir in northern Canada will emit the equivalent of between 400 and 700 grams of CO_2 per year—the higher figures corresponding to those reservoirs where peat bog dominates.

Is this worse than a fossil fuel plant? Again, it depends on how much land is flooded and how much electricity is generated. In another study, Rudd looked in detail at the Cedar Lake reservoir, part of the Grand Rapids hydroelectric project in northern Manitoba. He estimates that, over its lifetime, the greenhouse effect of the 1200 square kilometre lake will be almost identical to that of an equivalent coal-fired power station.

Critics say that Cedar Lake, like Balbina in Brazil, is an extreme case. Luc Gagnon of Hydro-Quebec, the company that runs the huge James Bay hydroelectric complex in Quebec, points out that Cedar Lake floods six times as much land for every megawatt of generating capacity as the James Bay reservoirs. And he says Rudd exaggerated the effect of methane emissions by assigning it a greenhouse effect 60 times that of CO_2, compared to Fearnside's factor of 11.

There is no one right way of doing this calculation. Rudd is simply reflecting the impact of methane over a shorter timescale. But Gagnon points out that if Rudd had used Fearnside's formula, it would nearly halve the calculated greenhouse effect of Cedar Lake's emissions.

Despite the different methodologies of Fearnside and Rudd, there is no denying that hydroelectric reservoirs are contributing to the greenhouse effect. Both scientists agree that the overall impact on global warming is too great to be ignored. And yet, so far, that is just what is happening. More than 150 countries have signed the Climate Change Convention and are currently negotiating national targets and timetables for reductions in emissions of greenhouse gases. To aid their work, scientists are preparing national inventories of current emissions. Reservoirs could prove to be a significant part of many nations' outputs of greenhouse gases. Yet, to date, no country has included emissions from reservoirs in those inventories.

Planet Earth Pictures

Brazil's Tucurui hydroelectric plant is half as polluting as a conventional power station

Flood plans

Balbina is not the only reservoir flooding huge areas to produce relatively small amounts of electricity. The Akosombo dam in Ghana has inundated more than 11 000 square kilometres of lush tropical vegetation, flooding an area equivalent to more than one soccer pitch for every kilowatt of capacity. In Russia, the Kuibyshev dam on the Volga floods half a soccer pitch for each kilowatt, and the Tsimlyansk on the Don floods two pitches for each kilowatt.

If all Canada's reservoirs emit as much greenhouse gases per square kilometre of their surface area as Rudd estimates, then over the next 50 years they will, on average, emit the equivalent of 13·8 million tonnes of CO_2. That would add 12 per cent to Canada's national emissions.

Brazil has plans for a massive reservoir-building programme in the Amazon region that would increase the surface area of the country's reservoirs twenty-fold. That, says Fearnside, would raise emissions of greenhouse gases from Brazil's reservoirs to the equivalent of more than 200 million tonnes of CO_2 a year—over three times the country's current annual emissions from burning fossil fuels.

Worldwide, the amount of land flooded by hydroelectric reservoirs is around 600 000 square kilometres—an expanse of water larger than the North Sea. At Canadian rates of emissions that would produce more than 400 million tonnes of CO_2 equivalent, or 7 per cent of total man-made emissions of CO_2. And with many more reservoirs planned, Fearnside warns that they are "a significant source of emissions of greenhouse gases that can no longer be ignored". □

'No country has included emissions from reservoirs in inventories of greenhouse gases'

Still Pictures

Still waters: Canada's La Grande river near the James Bay reservoirs