Earth's most important rivers are in the sky, and they're drying up

By Fred Pearce, *New Scientist*, print issue of Nov 2, 2019

The vast airborne waterways that keep our planet hydrated are fed by rainforests like the Amazon. If they disappear, the consequences may be worse than climate change

GERARD MOSS is a bush pilot in the swashbuckling tradition. Born in the UK and raised in Switzerland, he had flown twice round the world in his single-engine plane before he set out on a new journey, to track rain clouds across the Amazon in his adopted home of Brazil.

Local scientists had an idea: that the forests of the Amazon were the continent's biggest rainmakers; that most of the moisture in the clouds had been taken up and recycled back into the air five or six times by its 400 billion or so trees. Take away the trees, reasoned biologists such as Antonio Nobre, then of the National Institute of Amazonian Research in Manaus, and the rains would die. The Amazon basin would turn to desert. But with the rainforest largely a black hole for meteorological data, the idea was just that – until they hired Moss to equip his plane to collect water vapour.

Moss's flights over the Amazon a decade ago tracked the moisture-laden South American low-level jet, a concentrated air flow that Nobre called a "flying river". On one trip, Moss followed the jet for eight days from north-east to south-west across the rainforest, before tracking it east to Sao Paulo, the biggest city in South America. His data showed that the jet carried enough water in a day to supply the 20 million inhabitants of the metropolis for almost four months. Isotopic analysis revealed that most of that water had been generated by the rainforest. The role of forests in the world's water supplies was starting to come into focus. Alarm bells would soon be ringing.

We now know that flying rivers traverse the globe and influence rainfall over huge distances. And we are learning that forests play a key role in supplying them, which means that, in much of the world, the loss of the moisture recycling from deforestation is a more imminent threat even than global warming.

As Moss buzzed the Amazon's flying river, Dominick Spracklen was at a computer screen across the Atlantic at the University of Leeds in the UK. He was analysing meteorological data to tease out any relationship between rainfall and the amount of forest the air masses it fell from had passed over during the previous 10 days. His findings too were dramatic. Across most of the continental tropics, from the Amazon to the Congo basin to Borneo, air coming from forests delivered more than twice as much rain as air that had passed over deforested areas.

Of course, moist winds coming off the ocean usually bring rain. But the two investigators had trashed the long-held view that evaporation from the oceans is directly responsible for nearly all our precipitation. They showed that coastal winds rapidly dry out as they travel inland, unless there are forests to recycle the rain and keep the air moist. Spracklen says tropical forests recycle almost twice as much moisture as grassland.

“People once said that rainforests had high rainfall because they were located in wet parts of the world. Now it looks like forests usually make their own rainfall,” says Douglas Sheil, a forest scientist at the Norwegian University of Life Sciences. Vegetation on land – and especially forests – is the dominant source of the moisture that falls as rain over huge continental areas. The air flows that move that moisture are as big, in terms of the water they carry, as surface rivers, and travel even longer distances.

What emerges, says hydrologist Lan Wang-Erlandsson of Stockholm University, Sweden, is nothing less than “a new image of the global hydrological cycle”. The implications are stark. Deforestation is already reducing rainfall in large parts of the world. Large-scale forest loss could cut regional precipitation by up to 40 per cent, Spracklen reported in a paper last year.

In the Amazon, even partial deforestation would probably reduce rainfall by more than a fifth in the dry season. Not just in the rainforest itself, but for thousands of kilometres downwind too, across the soya and sugar plantations of southern Brazil and on into Paraguay, Bolivia, Uruguay and Argentina. Tropical forests are usually cleared to increase the land available for agriculture. The irony is that deforestation may ultimately make farming untenable over even larger areas. Far from rain “following the plough”, as a 19th-century adage had it, it seems the plough is more often the prelude to lost rains.

When first published a decade ago, few climate scientists took much notice of either Moss’s data or Spracklen’s modelling. Most researchers saw the climatic impacts of deforestation only in terms of extra carbon dioxide in the atmosphere. But that perception is changing fast, says Wang-Erlandsson.

“The loss of moisture from deforestation is a bigger threat than global warming”

It seems that large-scale clearing of vegetation by humans has created deserts before. Take the now-arid interior of Australia. It was much wetter until around 45,000 years ago. Today’s desert depressions were huge permanent lakes, kept full by strong and wet monsoon winds. Lake Eyre, also known as Kati Thanda, back then extended to around 10,000 square kilometres, but is now usually a dry salt-encrusted plain.

Global climate factors can’t explain the dramatic drying, says Gifford Miller at the University of Colorado. “The only variable that changed is humans colonised the continent.” He and Australian colleagues argue that the most plausible explanation is hunters burning bush to round up their megafauna prey. The loss of vegetation shut down moisture recycling and “weakened the penetration of monsoon moisture into the continental interior”, he says. As a result, today, “precipitation diminishes rapidly inland, to less than 300 millimetres within a few hundred kilometres of the coast”.

That interpretation offers a stark warning for other continents, not least South America. Australians, however, appear not to have learned the lesson. Much of the continent remains a hotspot for deforestation that may explain continuing declines in rainfall. In the past half century, some 130,000 square kilometres of forest along the western coast south of Perth has been replaced by wheat fields. While rainfall along the coast has remained stable, there has been a 20

per cent decline inland, leaving reservoirs that supply Perth parched, says Jorg Imberger, former director of the Centre for Water Research at the University of Western Australia.

Why does the loss of forest hold such sway over rainfall? Hydrologically speaking, trees are giant water fountains. A single tree typically transpires hundreds of litres of water a day. Transpiration is a process by which growing trees take water from the ground and release it into the atmosphere through their leaves. What has only recently become clear is that transpiration is a major source of water to the atmosphere, and is responsible for around half of all precipitation, up to 60,000 cubic kilometres of water a year, says Scott Jasechko at the University of California, Santa Barbara. "Transpiration moves more water than all the world's rivers combined," he says.

Indeed, some physicists say that the condensation of moisture in clouds above transpiring forests creates air pressure changes that draw in air and strengthen the winds that take the moisture inland. This idea, known as the biotic pump, has its detractors, but Deborah Lawrence at the University of Virginia says it suggests another reason why even small-scale deforestation, if it occurs in coastal areas, could disrupt the movement of moisture inland. Sheil says a weakened pump might explain declining surface winds seen across many land areas in recent times.

Clearly, in a world where forests are being lost and fresh water is in ever shorter supply, tracking atmospheric moisture matters. The first global attempt at this was made by Ruud van der Ent at Delft University of Technology in the Netherlands. He combined meteorological data with a computer model of atmospheric moisture flow to figure out the main source and sink regions for moisture and the routes of the main flying rivers that transport it.

Key source regions include western North America, eastern Africa, Europe, western Asia, India and, above all, the Brazilian Amazon. Flying rivers often take this water long distances. Around 70 per cent of the water in the River Plate basin, which stretches from southern Brazil through Bolivia, Paraguay and Uruguay to Buenos Aires in Argentina, comes from transpiration in the Amazon. China gets the moisture for over 80 per cent of its rain from far to the west in the forests of Siberia and Scandinavia, a journey involving several stages of water recycling by trees and taking six months or more.

"Transpiration moves more water than all the world's rivers combined"

"The China finding was among my first, and it was a real eye-opener," says van der Ent. "We learn in high school that rainfall comes from the oceans. China is next to an ocean, yet most of its rainfall is moisture recycled from the land far to the west."

Transpiration from forests may be crucial for relieving droughts and ending dry seasons, says Wang-Erlandsson. When there is no rain, evaporation from soils, and transpiration from shallow-rooted grasses and crops, ceases. But tree roots tap into water deeper underground. So trees keep transpiring, providing moisture to relieve drought downwind. No trees means more drought.

This isn't just speculation. "In the Amazon, the dry seasons are getting drier," says Jessica Baker at the University of Leeds, UK. And longer. Where forests have been replaced with cattle pasture and soya fields, they last an extra month. The worry is that beyond a tipping point – some models

suggest a 20 to 25 per cent loss of forest could be critical for the Amazon – tree loss could turn the climate into one where only savannah grassland thrives.

The Amazon is unlikely to be alone. In South-East Asia, deforestation has removed half of Borneo's forests in the past half a century. That has coincided with declining rainfall, with both trends accelerating since the 1970s. "Watersheds with more than 15 per cent forest loss had a more than 15 per cent reduction in rainfall" compared with those with intact forests, says Clive McAlpine of the University of Queensland, Australia.

The central African region, more dependent on moisture recycling than the Amazon, has seen a persistent decline in rainfall and coinciding with forest loss. The Congo rainforest transpires water that provides vital rains for many arid regions to the north, including the Ethiopian highlands, the main source of the Nile, and its loss would and drastically diminish the world's longest river. It might also be the last straw for the Sahel region on the southern edge of the Sahara desert, which Lawrence says may already have been deprived of rainfall by the past destruction of the rainforests in coastal West Africa.

These days, we talk a lot about how deforestation will release carbon dioxide and accelerate global climate change. Quite right. But its impact on moisture recycling may also disrupt weather systems on an intercontinental scale. Roni Avissar at the University of Miami in Florida has shown that Amazon deforestation is likely to damage rainfall in the US Midwest grain belt, and others have shown that it could halve the snowpack in the Sierra Nevada mountains.

"What may really be required is a new way of managing the world's water"

"None of this should be a surprise," says Avissar. "We know you get similar long-distance effects from El Niño events in the Pacific, which arise from changes in evaporation quite similar to those caused by deforestation."

Even so, the links between deforestation and the drying of landscapes aren't automatic. There are sometimes trade-offs. If trees extract water from soils and pour it into the air, there is less left to flow into local rivers. Downwind rainfall may be at the expense of downstream flows – that is one reason why deforestation can increase flood risks. Also, some crops commonly grown on deforested land, such as palm oil and rubber, can transpire more than the trees they replace.

The expanses of water flooding irrigated fields may have much the same effect, counteracting deforestation. One modelling study reckoned that up to 40 per cent of rainfall in parts of East Africa today comes from water evaporating from the irrigated expanses of India. Another found that the moisture lost from the irrigated Central Valley in California contributes 30 per cent of the flow of the Colorado river to the east, from where much of it is pumped back down canals to irrigate crops in other parts of California.

Megacity drought

So how should the world respond to this new hydrology? Clearly, preventing deforestation in key regions that supply water to the rivers of moisture-laden air that bring rain is vital. Water supplies in some of the world's megacities, including Shanghai, Karachi, Sao Paulo and Delhi, depend on moisture recycling from sources in distant countries. Some researchers believe they

know enough to target forest restoration in places that will increase rainfall in water-stressed places far downwind. Wei Weng at the Potsdam Institute for Climate Impact Research in Germany calls it “smart reforestation”. She says planting 70,000 square kilometres of extra forest in the Bolivian Amazon could deliver 600 million cubic metres of extra rain annually to a river supplying the country’s largest city, Santa Cruz, one of Latin America’s fastest-growing urban areas. The city’s authorities are considering a trial, but Sheil warns that “if we assume we can just replace natural forest with plantations and irrigation, we are playing a dangerous game with a system we don’t yet fully understand“.

What may really be required is a new way of managing the world’s water, one that recognises that rivers on the ground depend on those in the sky. Currently, rivers are managed individually within their river basins, as if the rainfall was a given. But in reality, these basins are interconnected by flying rivers. Land use in one river basin is critical to water supply in another. Water management needs to reflect that.

In a world running short of water, this matters now. During a serious drought in 2015, Sao Paulo almost ran out of water. The largest reservoir supplying the most populous city in the western hemisphere was down to its last 5 per cent, and city authorities blamed deforestation in the Amazon. It was a close call. For now, what happens in the Amazon still seems far away for most people in cities like Sao Paulo. But that may soon change.