Water: A long dry summer

In parts of the world already facing unreliable food supplies, an uncertain climate adds to the future stress for soils, plants and people. Quirin Schiermeier reports on water strategies for a drier world.

Quirin Schiermeier

Feeling the heat: the frequency of droughts like that seen in Europe in 2003 is likely to increase.*J. P. ARLES/REUTERS*

The record-breaking European heatwave of 2003 did not come out of the blue. It was preceded by an unusually dry spring during which soils dried up across the continent. The lack of moisture resulted in strongly reduced soil evaporation and cooling, which in turn intensified the temperature extremes during the summer.

Climate scientists believe that in the second half of this century, extreme summer heat and drought could become the rule rather than the exception as global temperatures rise. In any case, rapid loss of soil moisture early in the year now seems to be a signal for subsequent summer heatwaves in Europe[1]. A feedback loop appears to be at work: as heat dries up the soil, the dry soil amplifies the heat.

Changes in soil moisture content may have other feedbacks, affecting soil erosion, surface runoff, soil nutrients and even cloud formation. But predictions of soil drying in response to rising temperatures are still very uncertain. For Africa and South America, climate modellers are not even confident about the sign of the simulated changes.

“We are told climate variability will increase and that it may get drier in some regions, but we really know too little about the details,” says Malin Falkenmark, a hydrologist and water-management expert at the Stockholm International Water Institute in Sweden. This uncertainty hasn't stopped Falkenmark, along with other hydrologists, from recommending changes to water-management practices in response to climate change, and to declare an end to the wait-and-see approach of the past[2].

“We don't know for sure how climate change will unfold, but there's no doubt any more that it is happening and that there needs to be some preparedness,” Falkenmark says. “River flow in some dry regions may decrease by up to 40%, for example. That must alter water-resource planning methods. We cannot just wait until it happens.”

Current models suggest that more rain will fall, but less often, leading to longer periods during which soil moisture is critically depleted. Observations from several regions, including North America, Europe, southern Africa and Australia, confirm a trend towards heavier rainfall events, with longer dry periods in between, particularly during the summer[3].

Down to earth

Observable trends for soil moisture are more elusive. As yet, soils seem to be more resilient to global warming than, say, mountain glaciers or polar ice sheets. In the few regions where good records are available — such as the Ukraine, where scientists have measured soil moisture for 45 years — researchers have found no evidence for much of a downward trend, if any.

“Soil moisture is not an easily measured quantity,” says Jerry Meehl, a climate researcher at the US National Center for Atmospheric Research in Boulder, Colorado, and a lead author for the Intergovernmental Panel on Climate Change (IPCC). “The IPCC first predicted increased mid-continental summer drying of soils almost 20 years ago,” he notes. In the absence of observations to support or refute this prediction, the science has not advanced much since then.

Climate models are consistent in predicting greater summer soil dryness after 2050 in parts of every continent except Antarctica. But where that will change, and how much, depends heavily on the model (see maps), none of which are yet good enough to allow detailed soil moisture predictions at the river-basin scale or below — the scale that matters to water-management experts such as Falkenmark.

Click for larger picture.

The main reason for the fuzziness is that it is much more difficult to model rainfall than temperature. The processes that control rainfall, such as cloud and droplet formation, occur on much smaller scales than are used by existing climate models. Soils are also too patchy to be reliably represented in current models. Finally, the complex interactions between rainfall, evaporation, carbon dioxide concentration, plant growth and soil moisture are not easily computerized.

Because soil moisture and rainfall influence each other, the models desperately need better soil data to improve. Yet the world's soils are not nearly as well monitored as temperature or precipitation; *in situ* observations are few and scattered. To disentangle the complex interplay, scientists would need to find some way to measure soil moisture content directly and continuously.

There is hope that satellite measurements will help. Both the European Space Agency (ESA) and NASA are planning missions to observe soil moisture, expanding the work of ESA satellites ERS-1 and ERS-2. The microwave sensors on board the planned missions will give almost global coverage of soil moisture changes in real time. Where dense vegetation hides the soil, greenness can be used as a substitute.

At the same time, increasing computer power is allowing researchers to improve their models. There's still some way to go, admits Peter Cox, a climate modeller at the University of Exeter, UK. Current models are not yet fine-grained enough to model individual tropical storms, for example. But Cox says that some regional models are getting close.

“The trick is to use various sources of information and fuse them together so as to construct a global data set,” says Cox. “As climate models and satellite observations are converging in scale and resolution, we can start ingesting satellite data into our models and make them more powerful.”

The public usually associates water shortages with a lack of drinking water. But global water scarcity is primarily an issue of hunger, not thirst. Declining soil moisture generally means an increasing risk of drought. Monitoring and understanding possible soil moisture changes is therefore vital for crop management in all regions at risk of water scarcity.

“In Africa, 'rainy season' means that rain can fall, not that it will fall.”

Malin Falkenmark

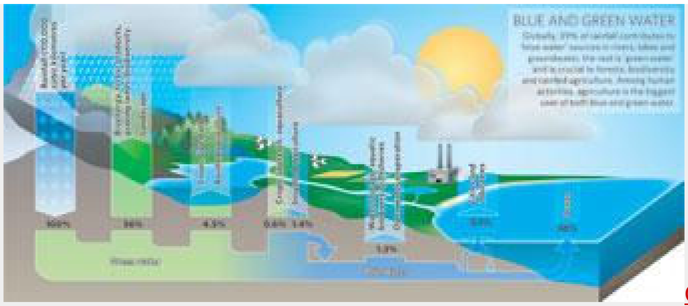
Researchers expect the most severe impacts to occur in the transition zones between wet and dry climates. In very wet regions, where soil water is always plentiful, evaporation and precipitation are hardly sensitive to soil moisture. And in very dry regions the rate of evaporation is too small to generate much precipitation anyway.

In one of the best available estimates, a multi-model study conducted by the Global Land–Atmosphere Coupling Experiment, run by the World Climate Research Programme, the hot spots of coupling between soil moisture and precipitation appear in the plains of North America, sub-Saharan Africa and northern India[4]. These regions, and in particular the 'hunger belt' from the Sahel to the Horn of Africa, are thought to be most at risk from the effects of climate change, such as more frequent droughts and floods, and accelerated soil erosion.

Soils store rainfall in the root zone of plants. This is called 'green water', as opposed to the blue water in rivers, lakes and groundwater stores. In dry regions, blue water is usually very scarce, often accounting for less than 10% of the overall water balance. All rain-fed agriculture in tropical and savannah regions, where irrigation is minor, depends on soils' capacity to capture what little rain falls.

“Green water is the key to water and food security in drought-prone regions,” says Falkenmark, who coined the term in the early 1990s. But experts believe that only 10–30% of rainfall in the world's savannah belt — the dry to moderately wet zones on all continents — is being used in a productive way.

The effect of climate change on water scarcity in regions that lack food security is becoming evident. Given the degree of human interference with climate and water, Falkenmark and other international experts recently declared dead the idea that water planners need consider only natural variability (and not human influence) when managing water supplies[2]. What the developing world needs now is a second 'green revolution', aimed at increasing yields by improving green-water management, soil conservation efforts, and more efficient protection of crops from prolonged dry spells, she says.



Click for larger picture.*Source: International Water Management Institute*

Green and blue water are not separate resources, of course. Irrigation turns blue water into green (see graphic). But in dry regions it is difficult to improve water availability through engineering works such as dams. “It is very unsatisfactory, therefore, that most water engineers are still mainly thinking in blue-water terms,” says Falkenmark.

To capture green water in dry African regions, farmers need to make sure that enough rain can infiltrate the soil after dry spells, for example by adopting more soil-friendly ploughing techniques, which have already increased yields in Latin America. And experts recommend that farmers harvest water from local runoff to use during dry spells in the growing season (see 'Keep it simple').

Going green

Even without climate change, rain in the savannah belt is erratic. In sub-Saharan Africa, for example, dry spells typically occur even in 'wet' years. “In Africa,” says Falkenmark, “the term 'rainy season' means that rain can fall, not that it will fall.”

“Global water scarcity is primarily an issue of hunger, not thirst.”

For soil moisture and green water, the local frequency and intensity of rainfall are at least as important as the total amount of precipitation. Heavy rain cannot penetrate parched and crusted soils, and without efficient water and land-use management, researchers warn that more variable rainfall in vulnerable regions threatens to increase runoff, erosion, water stress on plants and flooding.

Models agree that global warming will amplify the entire hydrological cycle, from evaporation to precipitation to runoff[5]. Global precipitation over land may slightly increase, especially in some northern latitudes or tropical regions, with a greater fraction occurring during the heaviest events.

Markus Reichstein, a carbon-cycle expert at the Max Planck Institute for Biogeochemistry in Jena, Germany, has studied the consequences of more extreme rainfall on ecosystems. He says all levels and processes of the ecosystem are likely to be affected, from runoff to soil evaporation and nutrient availability. Changes will affect all climate zones, but some ecosystems may respond very differently to others, a 15-strong interdisciplinary team concludes in its as yet unpublished review.

Plants' ability to adapt to changing water and nutrient availability might be crucial for their survival in a warming world. Ecologists think there are thresholds beyond which plants become stressed. But these vary between ecosystems, and so may plants' responses to climate change.


This irrigation system in Tanzania captures runoff water to boost water supplies in dry periods.*R. KAUTSKY/AZOTE IMAGES*

Soil water availability generally limits plant growth and photosynthesis. But nutrient availability in soils increases during dry spells, which suppress nutrient uptake by plants more severely than nutrient mineralization.

Still, in all semi-arid regions more extreme rainfall will increase stress on crops and vegetation, scientists believe[6]. Unfortunately, these are also densely populated regions with unreliable food production. In sub-Saharan Africa, longer dry spells will harm vegetation and, without supplementary irrigation, decrease yields.

A question of breeding

How best to adapt? The 2003 heatwave, which reduced yields in some European countries by more than 50%, shows that the rich world is not immune from the consequences of a warming climate, and from the need to adapt. But climate change is without doubt a much bigger threat to food security in poorer regions.

Experts warn that poverty tends to entrench the deficiencies of rain-fed agricultures in developing countries. As poor farmers cannot afford to invest in their crops, foreign investment aid or cheap loans are vital.

A recent analysis of climate risks for crops in 12 regions with food insecurity shows that crops such as oilseed rape, corn (maize) and wheat in south Asia and southern Africa are most vulnerable. Agricultural investment and adaptation efforts should focus on these crops and regions, the authors suggest[7].

“We're seeing a massive challenge,” says David Lobell, an agricultural ecologist at Stanford University in California and one of the authors of the study, who warns that plant breeding is under-resourced.

“We must urgently develop new crop varieties tolerant to heat and drought, and not just maize,” he says. “And we need to work hard and very quickly on it. Don't forget it can take 15 years of development effort until a new variety is adopted by farmers.”

But without prior investment in water and land management, crop-adaptation efforts will be less effective, says Deborah Bossio, director of research at the International Water

Management Institute in Colombo, Sri Lanka, and a lead author for the International Assessment of Agricultural Science and Technology Development, an international effort akin to the IPCC for agriculture.

Investment in water is particularly essential in south Asia and sub-Saharan Africa, says Bossio. And it should consider the full range of water storage and delivery options, she says, from the most local — soil water storage and farm ponds — to community projects such as small reservoirs.

But she warns that too much focus on crop production may put crops and livestock into conflict over water, with the risk that vulnerability is increased. “Livestock are always a very important component of the livelihood systems in areas at risk from water scarcity,” says Bossio. Adaptation to water scarcity has to consider all the components that affect people's lives.

Quirin Schiermeier is a reporter for Nature based in Munich. See Editorial, page 253 . For more see the Nature News Special on Water

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