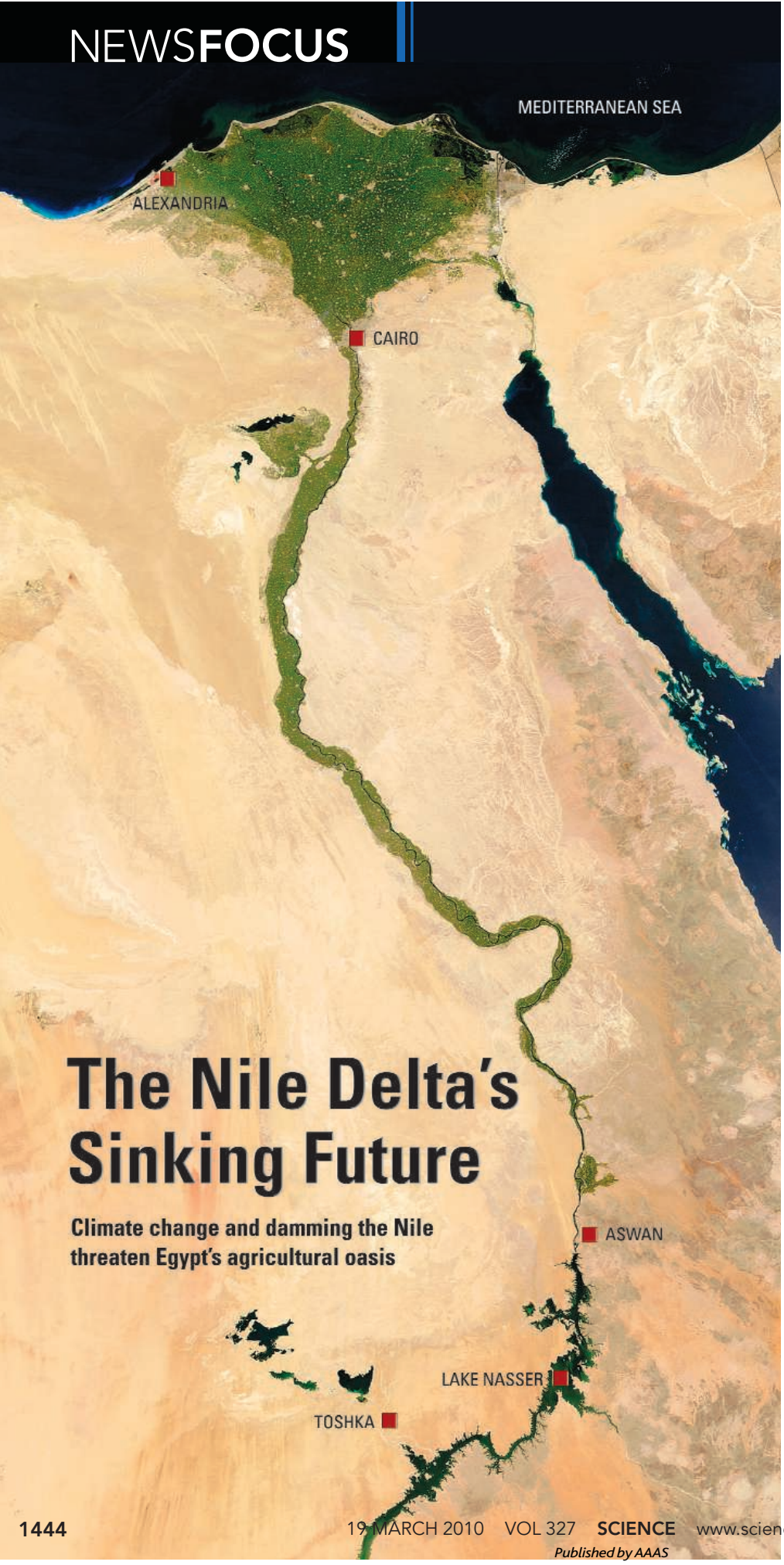


The Nile Delta's Sinking Future

Climate change and damming the Nile threaten Egypt's agricultural oasis

QALYUBIA, EGYPT—After fighting his way through Cairo's apocalyptic traffic to leave the city, Atef Abd El-Rahman's progress is stalled again, first by a donkey cart ambling slowly ahead and later by a shouting match among several men in the middle of the street. Finally reaching his destination, the engineer at Egypt's Ministry of Water Resources and Irrigation (MWRI) leaves the car behind and walks down a path into the quilted fields of a farm. The owner of the land, sipping tea in the shade of a tree, introduces himself as Fathy Abdelaleem. Abd El-Rahman praises the farmer's irrigation system, a network of troughs as intricate as a computer circuit, delivering water to his plants from one of the many canals feeding off the Nile River. Abdelaleem says he dug it and connected it himself to the canal: "Now I have no problem with water."

Here in the Nile Delta, starting just a few miles north of Cairo, the world's longest river divides into a fractal pattern of ever smaller rivers, canals, and irrigation ditches. Before the Nile reaches the Mediterranean, every drop of water is put to work by ingenious delta farmers like Abdelaleem, collectively known as the fellahin. Like most, Abdelaleem may have skirted a few laws while constructing his irrigation masterpiece—but then, few fellahin are even aware of the dizzying array of water regulations issued by Cairo. Environmental policing is "more difficult than you might think," says Essam Khalifa, a deputy director of MWRI. For example, he says, "two-thirds of the wells in the delta are illegal." A new law will mandate stiff fines for unsanctioned pumping, though similar efforts have had little effect.

Online
sciencemag.org
Podcast interview with author John Bohannon.

The only aspect of the Nile Delta over which the government exercises firm control is the input of water. The Nile was first dammed by the British in 1902 at Aswan. The Egyptians began construction on the far more massive Aswan High Dam in 1960 with the help of the Soviet Union. The hydroelectric dam changed life dramatically in the delta. It provided electricity and flood control to one of the most densely populated areas in the world. "Most people agree that it was for the better," says Farouk El-Baz, an Egyptian earth scientist based at Boston University.

Yet as Egypt celebrates the 50th anniversary

Fragile oases. Only 5% of Egypt's land area is inhabited, and some 50 million people pack into the delta north of Cairo that draws life from the waters of the Nile River.

CREDITS: NASA

Published by AAAS

of the start of the High Dam's construction—it took 10 years to complete—some scientists say that this wonder of engineering is contributing to an environmental catastrophe that could force millions of fellahin to abandon the lush, fertile delta. "It is now clear that [the High Dam] is having negative impacts," says Wahid Moufaddal, a remote-sensing scientist at the National Institute of Oceanography & Fisheries in Alexandria, Egypt.

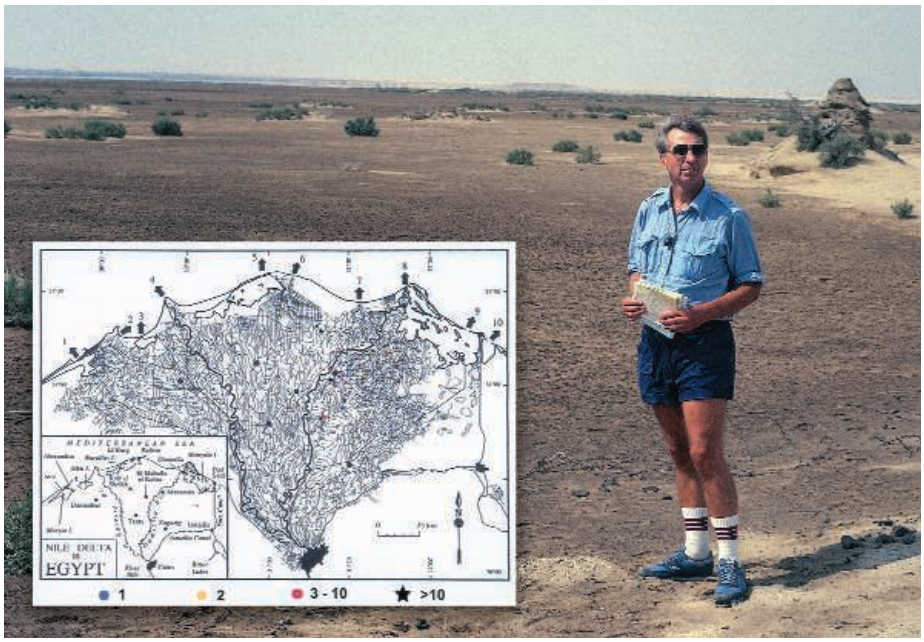
The worst of these is coastal erosion and subsidence, the compacting of the delta soil. For millennia, the untamed Nile compensated for these natural processes by delivering fresh sediments along with its fresh water. The dam, however, now blocks the sediments far upstream of Cairo. As a result, the delta is sinking. Today, 30% of the land is less than a meter above sea level, and in some areas close to the Mediterranean coast, it is sinking by nearly a centimeter per year.

At the same time, the Mediterranean Sea is expected to rise as a result of global warming. If the sea level increases by a meter by 2050, which is in the range of mainstream predictions, one-third of the delta could be lost. Meanwhile, the population here is growing by a million people per year—the delta is already home to 50 million, most crammed into an area no bigger than the state of Delaware. Because of these perfect storm conditions, the Intergovernmental Panel on Climate Change in 2007 named the Nile Delta among the three areas most vulnerable to climate change. "If we continue with business as usual, the impact on the delta will be devastating," says Mounir Tabet, director of the United Nations Development Programme (UNDP) in Egypt.

Deciding on a course of action is easier said than done, because the rates at which the sea is rising and the delta is sinking are subjects of fierce debate. As a first, cautious step, Egypt and the United Nations are this year launching a 5-year study of the options for protecting the delta from the encroaching sea. "We do not have enough data to advise policy yet," says Tabet. But as Egyptian scientists rush to provide those data, the government is steaming ahead with a series of "megaprojects" to boost the country's habitable area. In the most ambitious of these, the largest pump in the world is diverting 10% of the Nile into an uninhabited region of the desert to create a new delta.

Taming the Nile

Because the river is fed by the variable rains of the vast eastern and central African highlands, the Nile's pulse varies with the seasons and even longer cycles. "The Bible describes a 7-year cycle of flood and drought," says El-Baz. "And we now know that there really is a cycle that varies between 4 and 11 years." That makes life on the delta a gamble. Before the High Dam, floods wiped out homes and farms, while droughts brought famine and disease. But with their hands firmly on the faucet, Egyptians have tamed the Nile. An entire generation has never seen a flood. Instead, steady irrigation is now possible throughout the year. Rather than just one crop, delta farms can grow as many as three. Abdelaleem says he rotates wheat, taro, and clover on his.



Every drop used. By mapping the canal network of the Nile Delta (*inset*), geologist Jean-Daniel Stanley discovered how farmers use the water so efficiently that the river no longer reaches the sea.

At the time, the damming of the Nile raised few concerns. "There was no discussion" about the merits of such a potent source of pride for the newly independent nation, says Moufaddal. "It was a giant experiment," yet, he notes, there was no plan for collecting environmental data.

Moufaddal recalls that the first "whisperings" about a negative impact began in the 1980s. "Off the coast of the delta, our very important fishery for sardine and anchovy started dying." Pointing to a graph of the annual fishery harvests, he says, "you can see that it later made a big recovery." These fluctuations remain a riddle. "The best theory is that the fish crashed when the dam stopped the sediments and then recovered because of plankton blooming from sewage," says Moufaddal. But the gathering of environmental data has been so scant, he adds, that it is difficult to know "what is a direct cause of the dam and what is natural variation. We have no baseline data from before 1964." El-Baz puts it more bluntly: "No one gave a damn before the dam about science."

Complaints about the government's environmental research policies are a common refrain here. "What frustrates me as a scientist is that our government has blocked us from studying the problems," says Moufaddal. "If I want to attend a conference abroad, or even to take my research ship out to do sampling, it is sometimes a year before I have permission." Moufaddal concedes that some caution in doing fieldwork off the coast is reasonable, considering the animosity between Egypt and neighboring Israel. "But I am often not allowed even to take soil samples right here in the delta. How is that a security issue?"

Master of water. Delta farmer Fathy Abdelaleem looks over his irrigation ditches.

CREDITS (TOP AND INSET): JEAN-DANIEL STANLEY; J. BOHANNON/*SCIENCE*

Published by AAAS

Now that climate change is considered a major threat to the country's security, attitudes may be changing. "The government is relying on Egyptian scientists," says Tabet. The problem is that scientists do not have simple advice to give.

Rising seas, sinking land

"We used to relax all day on the beach right there," says Moufaddal, pointing to a rough patch of surf. From his perch on Alexandria's new seawall, the coast of the Nile Delta stretches to the east as a seemingly endless row of hotels and apartment buildings. He scrambles down to the city's original seawall, now crumbled and licked by the Mediterranean waves. "Here it is obvious that we are losing our coast to erosion," he says. "And if the water keeps rising, we have a problem."

The cost of control. Now that the Nile no longer floods the delta, pollution in connected canals (*left*) and coastal erosion (*right*) are growing problems.

The scientific consensus is that the Mediterranean will indeed rise as part of a global increase in sea levels, but how far and how fast is another matter. "What we do know is that the temperature of the ocean is increasing," says El-Baz, and water expands as it warms. "So this part is easy to predict." More worrying to climate scientists than this thermal expansion is whether global warming will trigger the ice on top of Greenland and Antarctica to break up and slip into the water. That is why forecasts for sea-level rise by the end of this century have ranged between 0.2 and 2 meters (*Science*, 5 September 2008, p. 1340). The former would be a manageable nuisance for the delta, whereas the latter would be catastrophic, all agree.

Predicting the future location of Egypt's coastline is especially complex because of the uneven sinking of the land. Yet while scientists may disagree about the rate of sinking, few are optimistic. "The Nile Delta is now in its destruction phase," says Jean-Daniel Stanley, a geologist at the Smithsonian Institution in Washington, D.C.

Stanley became the original authority on this issue after he undertook the first comprehensive study of the delta's geologic history in the 1980s. The delta is defined by the Nile's two main branches, which split just north of Cairo—one heading northwest to Rosetta and the other northeast to Damietta. During his fieldwork, Stanley noticed marine barnacles thriving kilometers inland within the river's outlets. "I was shocked to realize that the Nile was no longer flowing into the sea," he says. "Where was all that water going?"

Stanley requested a detailed map of all the waterways between Cairo and the Mediterranean. To his surprise, no such map existed. So with the help of several colleagues, he made one himself. The picture that emerged was like the dense filigree of neurons in a brain, with more than 10,000 kilometers of canals and diversions branching into every corner of the delta. The reason the Nile no longer reaches the Mediterranean, he says, is the efficiency of the fellahin. With the flooding stopped, says Stanley, "they use every last drop."

The Nile's flooding may have been destructive, but it was also crucial for the health of the delta. Before 1960, the Nile delivered an average of 100 million tons of sediment each year to the Mediterranean. Although the prevailing eastward sea current constantly nibbles away at Egypt's coastline, the sediment from the Nile easily compensated for that loss. But by 1970, when the Nile had formed Lake Nasser upstream of the Aswan dams, "that process stopped completely," says El-Baz. "The sediment enters the lake and it's like hitting a brick wall. The water slows and the sediment dumps."

Before the Nile was dammed, the annual flood deposited a millimeter of fresh silt onto the delta's surface. Not only did it provide nutrients for the crops—now replaced by chemical fertilizers—but the annual thickening of the soil countered subsidence. "All river deltas subside," says Stanley. "The sediment beneath the surface is supercharged with water." As the water leaches out, the sediment compacts.

Stanley was the first to measure how much the delta naturally subsides, and he used that measurement to extrapolate the delta's future topography. He and colleagues dug 87 cores across the northern delta and determined the age of the layers going back 7500 years with radioisotope dating. The results revealed that the subsidence rates across the delta have been far from uniform over the ages (*Science*, 22 April 1988, p. 497). Around the Nile's northeastern outlet, Stanley estimated that the delta has subsided at an astounding rate of half a meter per century; in other areas, the sediments have barely moved.

"There's a hinge line that runs along the northern delta," says Stanley. "Between that line and the sea, subsidence rates are the highest." In a second paper in *Science* (30 April 1993, p. 628), Stanley warned that even a conservative forecast of the rising seas and subsiding land "augers poorly for the delta." For example, a relative sea level increase of 1 meter would flood more than 30% of the region's land surface, he says. "But predicting exactly where it will flood is difficult," says Moufaddal, because different parts of the delta are subsiding at different rates.

Adding to the complexity, the historic subsidence rates Stanley calculated contain various uncertainties related to the radioisotope dating method. As a reality check on the rates, Stanley is now dating sediment layers with archaeological material such as pottery shards. But reliable traces of ancient human settlement are hard to come by here.

Some scientists are trying a completely new approach to gauging how fast the delta sinks. Rather than averaging the subsidence rates over the past millennia, Richard Becker and Mohamed Sultan, geologists at Western Michigan University in Kalamazoo, calculated the current subsidence in the delta. They used satellite-based radar interferometry to measure the rate at which the surface sank between 1992 and 1999. The technique, which uses multiple radar images to measure changes in the altitude of thousands of landmarks such as buildings and utility poles, is

Published by AAAS

sensitive enough to detect movement as small as 0.1 millimeter per year. The results, published in the September 2009 issue of *The Holocene*, found higher subsidence rates than Stanley calculated, suggesting that some areas could be submerged sooner than already feared. In particular, the fastest rates were in the youngest sediments, such as those beneath the coastal city of Damietta.

Even if one accepts these current subsidence rates, predicting the future topography of the delta may be impossible, says Stanley. Besides the steady leaching of water from the top layers of sediments, he says, "there are things happening deep below." Stanley suspects that sudden subsidence can be triggered when seismic jolts reorganize sediments laid down by the Nile long ago. "The delta we see is only the tip of a massive structure."

Going Dutch

In spite of the uncertainty, Egyptians are already planning for the future. "There are many options on the table," says Moufaddal. Some seem inevitable, such as the relocation of delta residents affected by coastal flooding. Others seem like science fiction. "One idea is to stop sea level rise by blocking the Mediterranean at Gibraltar," Moufaddal says, shaking his head. Moufaddal does not support even moderate plans for flood prevention, such as tidal gates, sea walls, and sand dunes. "You can't stop the sea," he says.

However, stopping the sea, or at least hampering its landward thrust, is what the Egyptian government is now pursuing. A $16 million pilot project, launched this year by Egypt and UNDP, will test some strategies for climate change "adaptation" in the low-lying delta. The 5-year project includes "strengthening of sand dune systems, beach nourishment, [and the] establishment of engineered wetlands," says Mohamed Bayoumi, the project's coordinator.

According to Stanley, saving the delta will require far grander schemes. "The Netherlands faced exactly the same situation," he says. One-fifth of the Netherlands is below sea level. After catastrophic flooding in 1953, the nation spent billions on the Delta Works, an elaborate system of dikes and storm-surge barriers designed to stop the North Sea from devastating the Dutch coast. "What Egypt needs is a Great Delta Works," Stanley says. But considering the price tag, "there's no way Egypt can afford it."

Even if the sea can be stopped, notes Stanley, the delta is facing a crisis in water quality. Without the annual floods flushing the delta clean, sewage, fertilizers, and industrial waste "go nowhere."

Problems also lurk below the delta. The Nile water that does not evaporate seeps down through the delta soil where it heads gradually for the Mediterranean like a sluggish mirror image of the river above. Because the canals are polluted, the fellahin use this naturally filtered water for drinking. But if too much water is sucked up for consumption, saltwater from the Mediterranean intrudes into the aquifer. A "salt wedge" is now creeping in, rendering well water as far as 30 kilometers inland too salty to drink. Without potable water above or below ground, says Stanley, "how are people going to live there?" In an effort to push back the salt wedge, Khalifa says that his ministry is encouraging delta farmers along the coast to switch to rice cultivation. Rice paddies are hardly an efficient use of limited fresh water, but as it soaks down, the fresh water can help block the sea where it intrudes.

Returning the Nile Delta to its natural state could solve these water problems, but "removing the dam is not an option," says Tarek Hussein, president of the Egyptian Academy of Scientific Research and Technology in Cairo. "One idea we are discussing is to divert sediments around the dam." Moufaddal says even that is futile: "Building up sediment will never keep up with rising sea levels."

Although the Egyptian government has never publicly said that the Nile Delta is doomed, it is creating a new delta in the desert. Upstream of the dams, 10% of Egypt's share of the Nile—amounting to 5 billion cubic meters of water per year—is being diverted southwest of Aswan to a desolate area known as Toshka. Because the land rises 30 meters between the river and the water's final destination, the government built the largest pump in the world to lift the Nile's water up to canals leading to Toshka. Since the pump fired up in 2005, more than 2000 square kilometers of desert have been irrigated. According to Moufaddal, however, Egypt hasn't seriously thought about the environmental impact of the project, which he fears could destroy desert habitats and hasten the demise of the Nile Delta by siphoning away its water. "We are repeating the mistake of Aswan," he says.

Egyptian officials view things differently. "Bringing life to the desert" is the goal of the Toshka "megaproject," says Khalifa. It is seen as crucial for meeting the government's goal of a 50% increase in the country's farmland by 2017. And by that date, according to a government brochure, 2 million people will be living at Toshka.

Megapump. Transporting water from the Nile to the Toshka megaproject requires the most powerful pump in the world.

"That's not going to happen," warns El-Baz. Besides temperatures that can reach 50°C, he says, "no one wants to live out in the middle of nowhere." The government is now promising free plots of land as an incentive for people to relocate to Toshka, but, says El-Baz, "no one is taking the offer." To increase the area's lure, he has proposed a "development corridor" of highways and electrical lines from Toshka to Cairo and Alexandria. It would cost $24 billion over 10 years. "Connecting Toshka to civilization is the only way to convince people to move," El-Baz says. Then again, if the worst predictions for the Nile Delta come true, millions of fellahin will be in need of a new home.

–JOHN BOHANNON

CREDIT: TERJE TVEDT

Published by AAAS