

Creating a Global D

by Madeline Fisher

On the wall of Alfred Hartemink's office at

the University of Wisconsin–Madison hangs a framed picture from 1960. The World Congress of Soil Science was in town that year, and a large group of soil scientists posed for a photo along the campus shoreline of Lake Mendota—the same lake Hartemink now sees every day from his office window.

The historical connection clearly pleases the Dutch soil scientist and SSSA member, who came to the university just last year after living and working all over the world—most recently at ISRIC-World Soil Information in Wageningen, the Netherlands. But the real significance of the 1960 meeting wasn't in the setting, but in what the group, known as the International Society of Soil Science (ISSS), decided to do.

Despite the rifts created by the Cold War and Suez Crisis at the time, "They said, 'Let's do something bold. Let's make a soil map of the world,'" recalls Hartemink, who is secretary general of the successor organization to ISSS: the IUSS, or International Union of Soil Sciences. And eventually they did, although it took 25 years. "That's the FAO-UNESCO soil map of

the world," he says. "The only one we have at the moment."

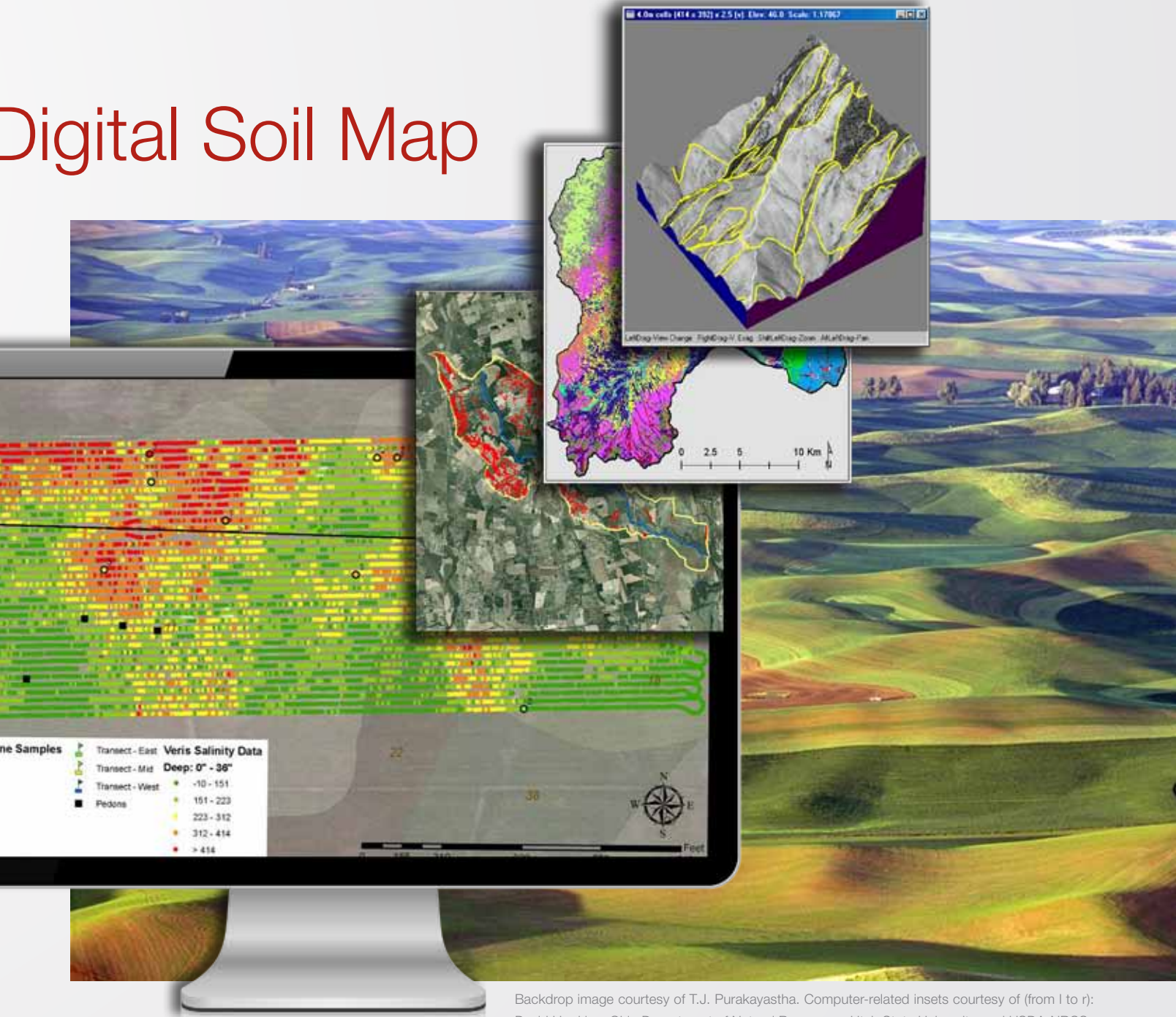
That may be true now, but a second map is on the way. For the past five years, in fact, Hartemink and dozens of other soil scientists worldwide have been working not only on another global soil map, but also a *digital* one this time: a fine-resolution spatial repository of data on pH, organic carbon levels, texture, and other soil properties that can be readily and continually updated.

Named *GlobalSoilMap.net*, the effort is somewhat like going from a 1980s printed road atlas to Google Earth in one giant leap, and there are major scientific and technological hurdles to overcome. Add the challenges of reaching consensus on methods, coordinating dozens of institutions around the globe, and surmounting geopolitical obstacles to data sharing, and "it's

quite an endeavor to produce a global digital soil map," says University of Florida soil scientist and ASA and SSSA member Sabine Grunwald, who leads an ASA Community focused on the project.

But the map is also desperately needed. Existing soil maps—like the FAO-UNESCO one—are often years or even decades out of date. More critically, the soil class information they contain can't easily be used by researchers in other fields, making it difficult to fully integrate soil science with hydrology, ecology, atmospheric science, economics, and other disciplines. Instead, scientists in these fields often produce their own

Digital Soil Map



Backdrop image courtesy of T.J. Purakayastha. Computer-related insets courtesy of (from l to r): David Hopkins, Ohio Department of Natural Resources, Utah State University, and USDA-NRCS.

estimates of soil properties “and that scares us,” says Hartemink, who led *GlobalSoilMap.net* from the Netherlands until last year.

“So often we see [in studies] that soils are either not treated at all or are treated as a 50-kilometer average across large chunks of space,” agrees Alex McBratney, a University of Sydney soil scientist and the project’s overall scientific adviser. “But we know that the variability of soils at

finer scales is actually important in the behavior of ecosystems.”

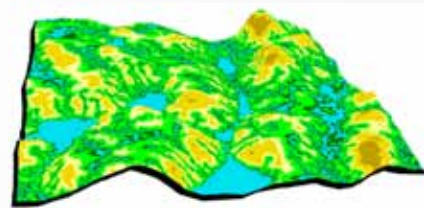
While this is frustrating, he adds, the real issue is how the lack of digital information hinders our ability to know the impact of soils on global climate change or predict the water-holding capacity—and thus, crop-growing potential—of soils worldwide. In other words, the group isn’t making the map merely because it can

or to prove to other researchers that soils are important.

“The real aim, and maybe we’re being idealistic, is to tackle those larger global issues,” McBratney says.

From Soil Classes to Soil Properties

To grasp the significance of the project, which officially launched in



New York in 2009, it helps to know something about traditional soil mapping. After surveying soils or studying aerial photographs, soil scientists draw boundaries on a map to designate areas, called “polygons,” where soils differ across a region. Based on the dominant soil types and properties within the polygons, each is then assigned to a soil class and named according to a taxonomic system similar to the one for plants and animals. For example, just as the potato’s scientific name is *Solanum tuberosum*, soil in what’s commonly called the Antigo series is classified as a “Haplic Glosudalf.”

Plants and animals are distinct beings, however, whereas different soils blend gradually into one another across the landscape, Hartemink says, making the polygon boundaries between them somewhat arbitrary. A bigger issue is that although soil maps and class names are invaluable to soil scientists, land managers, and farmers, they are less useful to modelers and other researchers who need quantitative, spatial data on pH, organic carbon, bulk density, and other soil properties.

“It’s quite difficult to get that information from the class. The name tells you relatively little about pH or

organic carbon content,” Hartemink says. “And there are a lot of people who are mainly interested in soil properties, but not classes.”

This is why the IUSS formed a working group nearly a decade ago to study and develop methods for digital soil mapping—which is not the same as digitizing existing soil maps. A true digital map doesn’t employ polygons, for one; instead, it’s broken into a fine grid of cells, or rasters, which typically range in size from 5 by 5 to 90 by 90 meters. Rather than a class name, each cell has an associated set of soil property data. And these soil values are often predicted from other types of data, such as climate, relief, and geology, rather than being directly measured.

Most importantly, when the global digital soil map is complete, it will provide a measure of the uncertainty associated with each soil property estimate, Hartemink says. For example, scientists will be able to say that the pH at a certain spot is 6.5 plus or minus 0.3, or “we’re 80% sure,” he says. “We’re very used to having a probability to the weather: A 40% chance of showers. But we haven’t done that a lot in soil science.”

Much of the holdup was that mapping and computing techniques

weren’t advanced enough for many years to produce a digital map on a very large scale, but in 2006, the IUSS working group thought the methodology might be ready. Near the end of a meeting in Rio de Janeiro that year, the group talked about attempting a digital map of the available water capacity of the world’s soils. One or two weeks later, they discussed the possibility again at the World Congress of Soil Science in Philadelphia. And by year’s end, they’d organized the first official meeting on the global digital soil map, chaired by ASA and SSSA Fellow Pedro Sanchez at Columbia University.

The meeting resulted in a proposal, which in turn attracted \$1 million in seed money from the Bill and Melinda Gates Foundation. (The foundation also gave another \$18 million to map the continent of Africa, where soil information is especially sparse.) The seed funds ran out before most of the scientific work began. But the money did allow the creation of a consortium and network of administrative “nodes” that now covers nearly the entire planet, says Neil McKenzie of Australia’s Commonwealth Scientific and Industrial Research Organisation (CSIRO), which assumed leadership of the project after Hartemink left ISRIC in 2011.

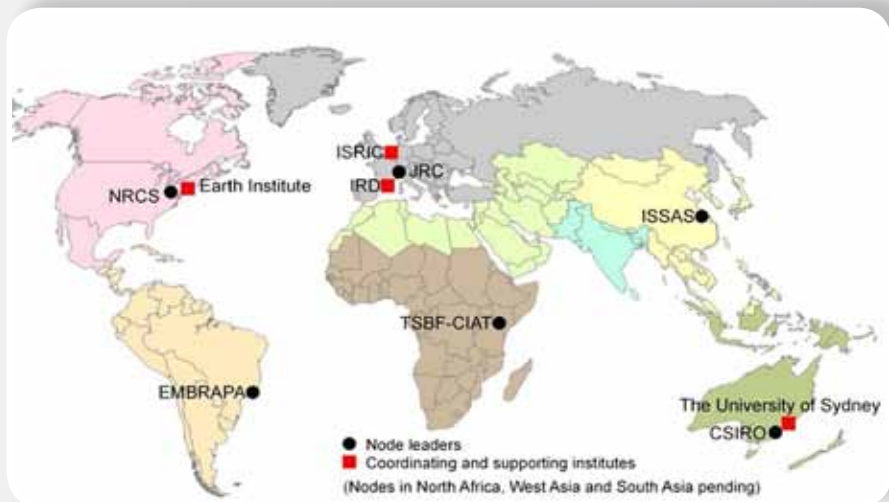
McKenzie and CSIRO, for example, lead the Oceania node; Jon Hempel of USDA-NRCS in Lincoln, NE, oversees the North American node; and Lou Mendonça Santos of EMBRAPA in Brazil directs the Latin American node. There is also a network of “supporting” institutes (see map) and dozens of partner organizations. In North America alone, for instance, more than 10 universities and agencies are involved, including Agriculture and Agri-Food Canada and the National Institute of Statistics, Geography, and Informatics in Mexico.

Indeed, in its scope and ambition, the venture is not unlike the Human Genome Project, whose completion also took the combined work of scientists and research institutions worldwide. Yet, while that project was fueled by vast sums of money—not to mention high-octane personalities like Craig Venter—*GlobalSoilMap.net* has so far been driven mainly by the commitment of the scientists, Hempel says.

“It’s amazing to me that we could pull together a consortium of people from around the world and stay together on the idea, considering the distance and communication issues,” says the SSSA member. “I mean, all of the nodes have remained engaged and are pretty dedicated to the concept.”

Sorting Out the Details

So what has the team been doing? “Although it probably seems dry, we’ve spent several years getting agreement on the technical specifications of the project,” McKenzie says. “We’re essentially building a very large system for providing web-based services relating to soil properties. So, the size of the dataset and how we generate the estimates of the properties is quite a large thing to sort out.” For example, the consortium has settled on a spatial resolution for the map of 100 by 100 meters, and it decided to offer data down to 2 meters, at six depth intervals: 0 to 5 centimeters, 5 to 15 centimeters, and so on.



GlobalSoilMap.net is organized into eight “nodes” around the world, led by scientists at the following institutions: USDA-NRCS in North America; EMBRAPA (Brazilian Agricultural Research Corporation) in Latin America/Caribbean; JRC (Joint Research Centre of the European Commission) in Eurasia; Jordan’s Ministry of Agriculture CUMERC in North Africa/West Asia; TSBF-CIAT (Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture) in Africa; ISSAS (Chinese Academy of Sciences) in East Asia; and CSIRO (Commonwealth Scientific and Industrial Research Organisation) in Oceania. A node leader for South Asia is pending.

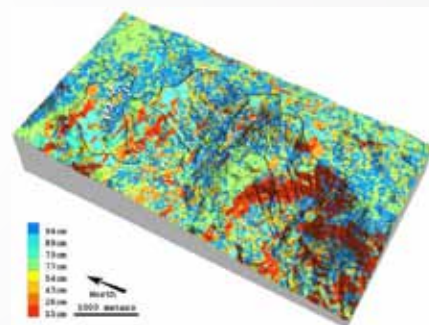
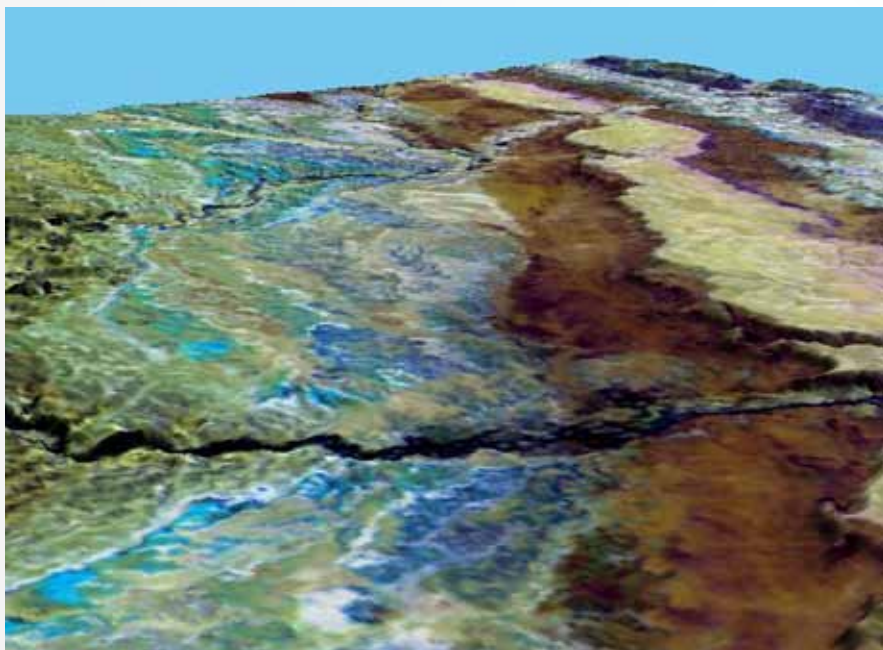
Several other institutions also help to coordinate the project: the Earth Institute of Columbia University in the United States; the University of Sydney in Australia; ISRIC in the Netherlands; and INRA (French National Institute for Agricultural Research), which recently replaced IRD (International Relief and Development) as a supporting institution of *GlobalSoilMap.net* in Europe.

Another key decision was which soil properties to focus on: They include organic carbon, pH, texture, available water capacity, and depth to bedrock or restrictive layer. Others, such as cation exchange capacity, can then be predicted by using what are called pedotransfer functions. “That’s why those particular properties were chosen,” Hempel says. “They give us the most flexibility in modeling other properties.”

If agreeing to all this on paper has been a challenge, however, it’s nothing compared with actually making the map. New scientific questions and problems have emerged constantly, McBratney says, such as how to model soil properties with depth (they’ve come up with an innovative solution, called the spline technique) and how to utilize and mesh together different types of data, including

actual numbers from soil analyses, class information from traditional soil maps, and data on climate, relief, and other environmental factors.

The second question is especially critical given the project’s aim of using a century’s worth of “legacy” soil information to the fullest extent possible. McKenzie explains that countries like Denmark and South Korea have sampled and analyzed their soils in exquisite detail, providing a rich supply of “point” data that are relatively easy to put into digital format. But in other countries, such as the United States, most soils data must be extracted from the polygon information in traditional soil maps. This involves converting the polygons into grids of cells, deducing from soil class information which soils are present within each polygon, and then



assigning soil properties to the cells individually.

In North America, much of the continent's existing soil class, or polygon information, has been converted to a grid format. However, until the polygons are "disaggregated" into different soil types, the cells created from individual polygons will all contain the exact same soil properties, Hempel explains; predicting how properties vary from cell to cell will come later.

But before the data are publicly released, there's another hurdle to surmount: calculating the uncertainty associated with each soil property value. This is tricky, McBratney says, because in addition to the uncertainty that comes from the inherent variability of the soil, uncertainty arises from the quality and density of the data itself. In regions where soils have been sampled and analyzed at high density,

uncertainty values are fairly easy to calculate with standard statistical techniques. But when soil properties are predicted from polygon information through the disaggregation process, not only is the uncertainty naturally higher, but computing it is tougher, as well. "So at our current stage, we are pretty good with the point data, but we're still figuring out how to deal with the disaggregation model," McBratney says.

Building Collaborations

Asked where the entire project stands, and McBratney falls back on a familiar line. "Let's say what all scientists say: In five years' time," he says with a laugh. "That's far enough away that it's not tomorrow."

"Everyone in the consortium would love for it to be going faster,"

adds McKenzie. "It's quite a challenging time to be getting large grants internationally as I'm sure people can well appreciate." Still, he notes, CSIRO is close to securing funding for a core technical team that will coordinate the implementation of the project worldwide. And, meanwhile, the transition in leadership that began when Hartemink stepped down as director is now complete.

One aspect of the global digital soil map project that many don't appreciate is how much time is spent in negotiations and diplomacy, McKenzie adds. Soils, he explains, are sovereign resources that play a huge part in each country's capacity to grow food and maintain clean water supplies. So, for this reason, a system where countries hand over their soils information to a central organization won't work. Individual countries instead have to be responsible for maintaining their own data, he says, or, if they can't, to be willing to collaborate with a partner country that manages their soils information for them. And then countries have to agree to share their data, which comes with its own sensitivities and complications.

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“So this is not a project that can be switched on overnight,” McKenzie says. “There’s a lot of building of collaboration and coordination around the world to make it happen.”

Whenever it happens, he and the others expect the impact to be substantial. With the Anthropocene—the Age of Humans—upon us, Grunwald believes the map will be a critical tool for knowing how soils are forming, changing, and degrading in response to human activities. The collaborations forged by the map between soil science and other disciplines should foster wide understanding of soil’s role in global issues like food security, biodiversity, drought mitigation, and climate change, Hempel says—as well as help address them. And because soils information is scant in many regions, Hartemink thinks the uncertainty associated with the map’s soil property predictions will frequently be high, sparking efforts to improve

For More on This Topic....

There will be two symposia focused on the global digital soil map at the Annual Meetings in October:

- **Global Soil Mapping in a Changing World: I** (part of ASA’s Global Agronomy program): <http://scisoc.confex.com/scisoc/2012am/webprogram/Session9682.html>
- **Global Soil Mapping in a Changing World** (part of SSSA’s Pedology program): <http://scisoc.confex.com/scisoc/2012am/webprogram/Session10052.html>

Also, check out **ASA’s Global Digital Soil Map Community** at www.agronomy.org/membership/communities/global-digital-soil-map.

the data with additional soil survey and sampling work.

Even before it’s finished, in fact, the global digital soil map seems to be making an impression. “We feel that there is a whole new generation of very capable soil scientists who are picking up on this project and starting to figure out how they can make

their countries’ data fit into the global system, whether they’re from Chile or Mozambique or Europe or elsewhere in the world,” McKenzie says. “That’s very heartening for us to see.”

M. Fisher, science communications manager

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