

Landsat

Continuing to Improve Everyday Life



Introduction

The Landsat Data Continuity Mission (LDCM) builds on a rich legacy of service to society. LDCM is the eighth satellite in the Landsat series and will be renamed Landsat 8 after launch. The mission will extend the more than 40-year-long Landsat record of Earth's continental and coastal landscapes. Since the launch of Landsat 1 in 1972, Landsat satellites have become an integral part of many operational land management activities. Landsat satellites provide decision makers with key information about the world's food, forests, water and how these and other land resources are being used.

This information helps forest managers decide how to allocate resources to restore a landscape after a wildfire, respond to insect infestations or disease, and slow deforestation. It helps state water managers identify sources of pollution related to land use. In western states, Landsat data shows water agencies how much water is being used to irrigate crops. Landsat images help agricultural agencies forecast crop production both nationally and globally. The launch of the LDCM satellite ensures that Landsat data will continue to enable these applications and to improve everyday life in a myriad of other ways.

LDCM carries two instruments, the Observational Land Imager and the Thermal Infrared Sensor, that together observe the same wavelengths of light as earlier Landsat satellites, but add two new "bands." These bands observe new parts of the electromagnetic spectrum that will improve cloud detection and observations of near-shore ocean chlorophyll. Additionally, the single thermal infrared band sensed by previous Landsat instruments is split into two thermal bands to help improve sensitivity to surface temperature. LDCM also improves the radiometric quality of the imagery, for example by increasing the number of bits used to represent each pixel value in an image.

The continuity of observations and the technological improvements ensure that LDCM meets the needs of Landsat's many user communities long into the future.



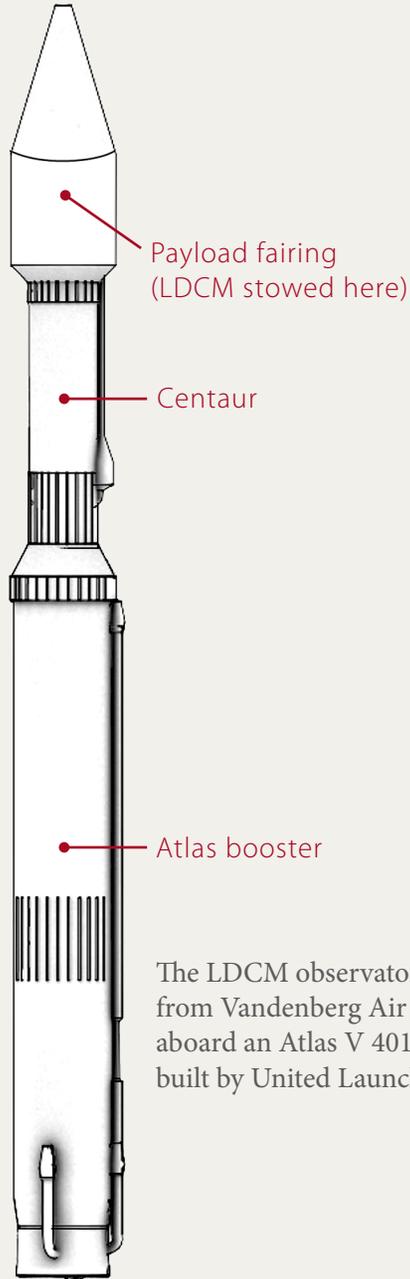
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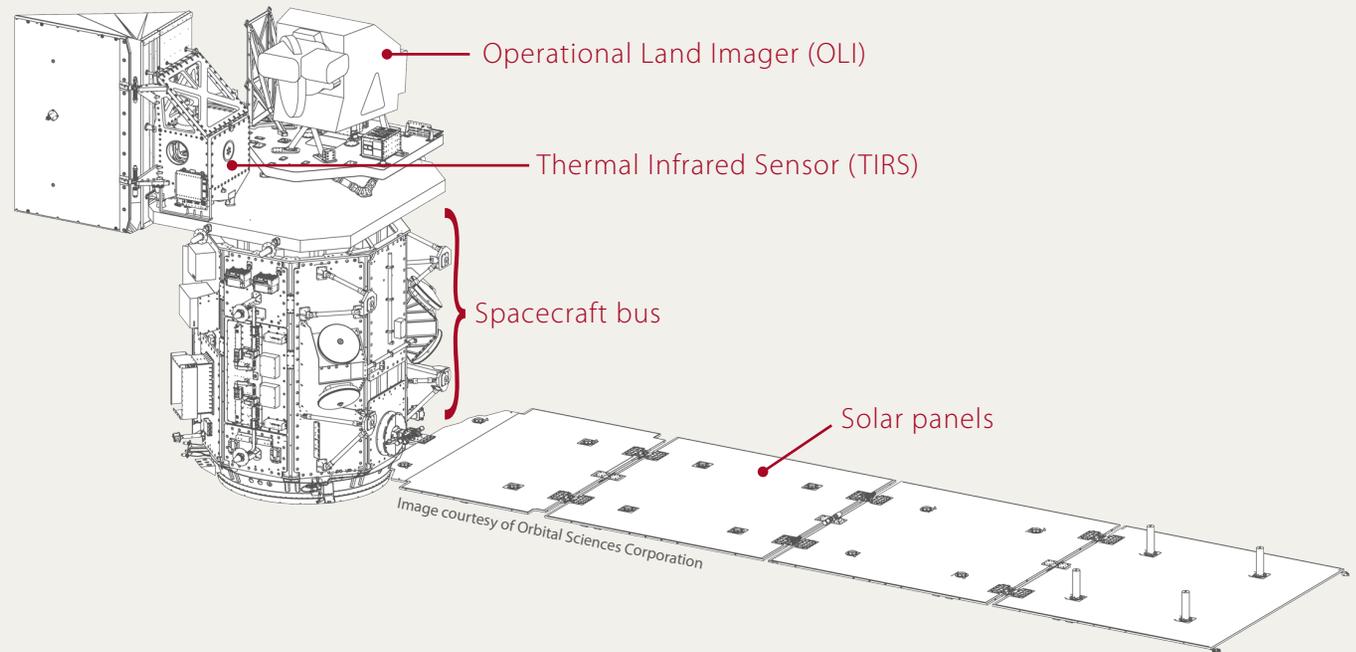


The LDCM

The Rocket



The Spacecraft

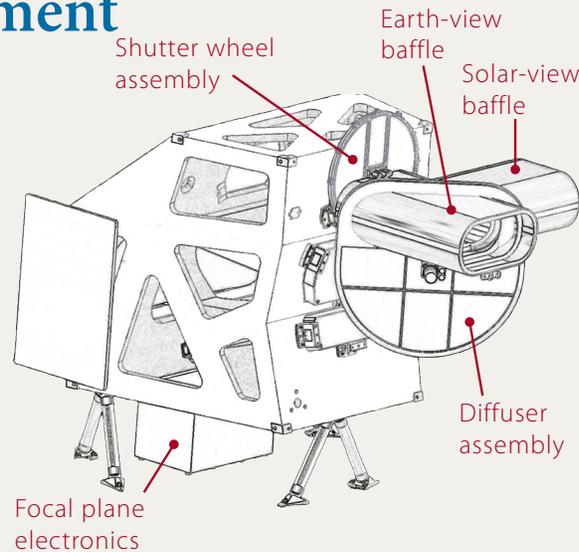


The spacecraft supplies power, orbit and attitude control, communications, and data storage for OLI and TIRS. The spacecraft consists of the mechanical subsystem (primary structure and deployable mechanisms), command and data handling subsystem, attitude control subsystem, electrical power subsystem, radio frequency (RF) communications subsystem, the hydrazine propulsion subsystem, and thermal control subsystem. The spacecraft was built by Orbital Sciences Corporation.

Hardware

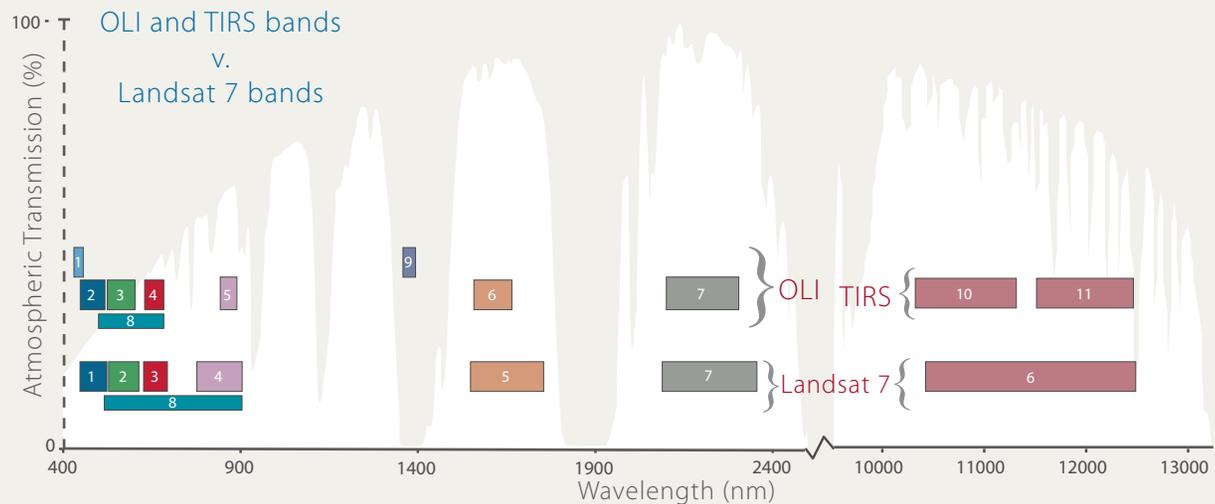
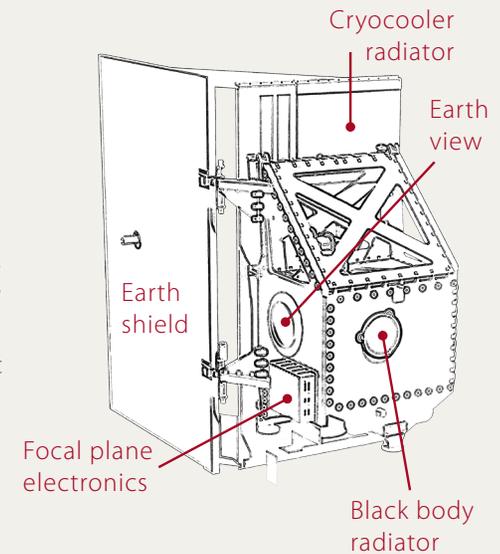
The OLI Instrument

The Operational Land Imager (OLI) is a “pushbroom” sensor that will use long detector arrays, with over 7000 detectors per spectral band, aligned across its focal plane to view across its 185 kilometer (115 mile) swath. Its images will have 15 meter (49 feet) panchromatic and 30 meter (98 feet) multispectral spatial resolutions. The OLI has a five-year design life and will detect the same spectral bands as earlier Landsat instruments with the exception of a thermal infrared band. In addition to the heritage Landsat multispectral bands, OLI will add two new spectral bands—a blue “coastal” band (band 1) and a shortwave-infrared “cirrus” band (band 9). These new bands will, respectively, help scientists measure water quality and help detect high, thin clouds. OLI was built by Ball Aerospace & Technologies Corporation.



The TIRS Instrument

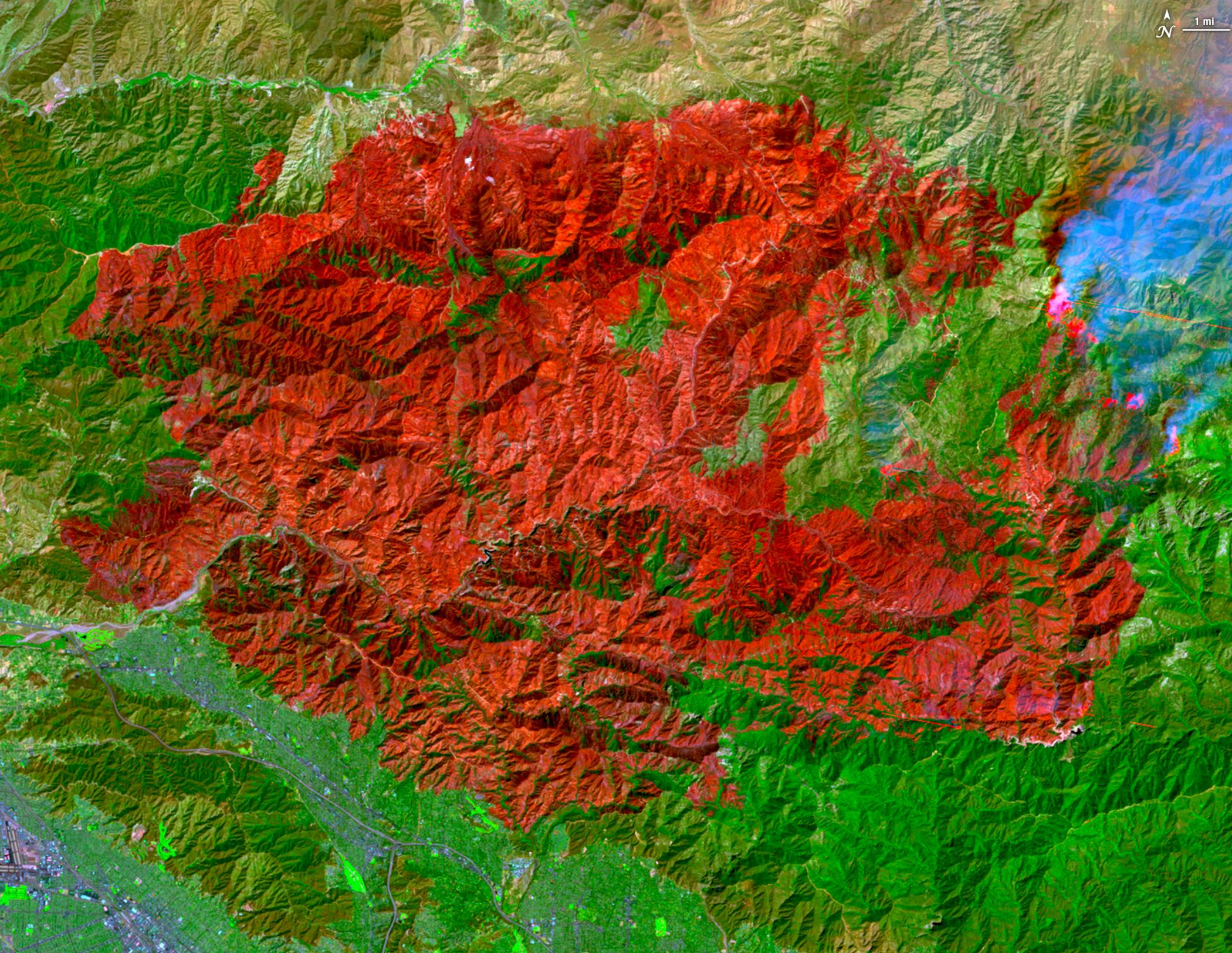
The Thermal Infrared Sensor (TIRS) is also a pushbroom sensor with a 185-kilometer cross-track field of view. Its spatial resolution is 100 meters (328 feet). TIRS detects energy in two thermal infrared regions. The instrument has a three-year design life. It was built in-house at NASA’s Goddard Space Flight Center.





The Station Fire burns in the mountains east of Los Angeles on September 7, 2009.

Opposite: By mixing infrared light with visible light, Landsat reveals the extent of the fire. Newly burned land is red, unburned vegetation is green, and LA is purple.





Burning Wildlands and a Burning Need for Landsat | Laura E.P. Rocchio

At 8 p.m. on Thursday, May 4th, 2000, after months of planning, fire boss Mike Powell ignited a routine prescribed fire at the Bandelier National Monument just outside of Los Alamos, New Mexico. The burn was intended to reduce hazardous fuel (like dead trees and accumulated brush) in the Upper Frijoles Creek drainage area on the eastern rim of the Jemez Mountains. Initially it went as expected, but in the early morning hours of May 5 the fire escaped the planned boundaries, and by that afternoon it was declared a wildfire. On May 10, a major wind event, with gusts reaching 60 mph, whipped the flames into a firestorm. At 5 p.m. that night New Mexico Governor Gary Johnson ordered Los Alamos to be evacuated. Three days later, President Bill Clinton declared the fire a major disaster.

The wildland fire, named the Cerro Grande Fire, would burn for a month before being contained on June 6, and it wouldn't be declared out until Sept. 22. In the end, nearly 43,000 acres would burn including over 25,000 acres of the Santa Fe National Forest, 15,200 acres of other federal lands—7,600 acres within the Los Alamos National Laboratory (LANL)—and 2,000 acres of private lands. The conflagration would destroy 235 homes and structures in Los Alamos and a number of temporary structures on the LANL grounds; fortunately no radiation or toxic materials

were released from the lab property. In total, Cerro Grande Fire damages exceeded \$1 billion and 400 families were displaced.

On May 11, 2000 with both the town of Los Alamos and a national laboratory containing on-site hazardous wastes threatened by a fire that had been intentionally set by the National Park Service, the Secretary of the Interior, Bruce Babbitt called for an interagency investigation. Babbitt, together with Secretary of Agriculture Dan Glickman, ordered a 30-day moratorium on all prescribed burns west of the 100th meridian.

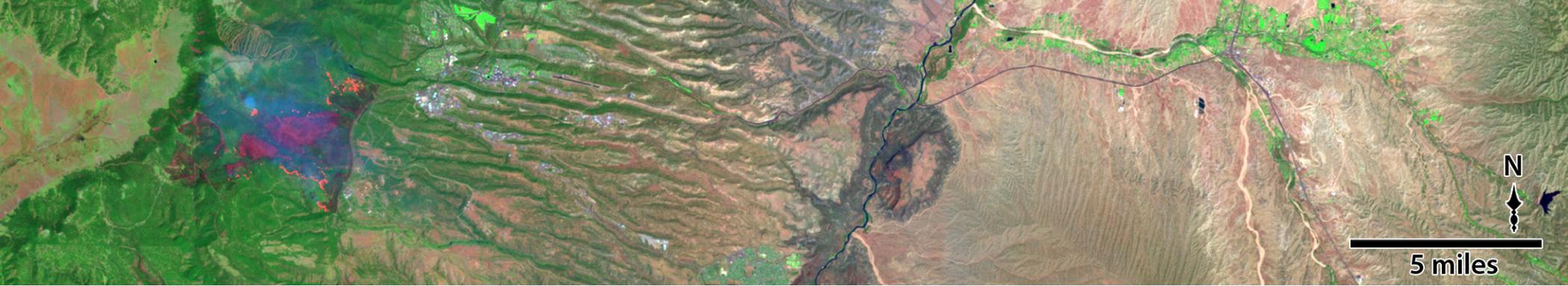
The investigation revealed a number of problems: the burn complexity rating that told the burn boss what to prepare for had been too low; replacement fire crews were brought on too slowly, there had been confusion over which agency should pay for fire fighting resources like helicopters and fire engines; and lastly, there was the devastating, unanticipated and unpredicted wind event.

After decades of fire suppression, federal wildlands had become virtual tinderboxes with enough fuel to unleash massively destructive fires. Planned, prescribed burns had become necessary, but the Cerro Grande fire had brought into question the safety of such prescribed burns. There had been a lack of coordination between

agencies in the patchwork of federal lands surrounding Bandelier National Monument. A NPS investigation, concluded that, “The Cerro Grande Prescribed Fire demonstrates the need for all land managing agencies to come to common agreement on future guidelines and protocols for dealing with complex prescribed burns and to advocate for the highest levels of interagency understanding, standardization, and cooperation.” Similarly, the interagency incident report recommended that an interagency burn complexity standard be developed and ratings be compiled for geographic regions instead of focusing solely on agency-owned lands. ▶



[Photo Information](#)
Opposite: A prescribed burn in Frijoles Canyon with the historic Tyuonyi Village pictured in the valley below. Credit: Sally King, NPS. Below: View from an ancient cave at Bandelier National Monument. Credit: Sally King, NPS. Above: Silhouette of firefighter at 2012 Bagley wildfire in California. Credit: Forest Service.



[Image Information](#)

Landsat 7 image of the Cerro Grande fire captured on May 9, 2000. The fire continued to spread and caused damage to the town of Los Alamos to its east. This image uses Landsat 7 ETM+ bands 7,4,2,

Enter Landsat

After Cerro Grande, President Clinton asked Babbitt and Glickman to devise the best path forward for dealing with wildland fires. The resulting National Fire Plan (today called the National Cohesive Wildland Fire Management Strategy) called for science-based planning for wildland fire management. But the following year, the General Accounting Office stated that, “Federal land management agencies do not have adequate data for making informed decisions and measuring the agencies’ progress in reducing fuels.”

An efficient, low-cost method for mapping and monitoring vegetation trends, fires, and fuel loads was needed. Land managers turned to Landsat. Since the 1980s the Landsat satellites had been regularly collecting and archiving data about Earth’s land surface at a 30-meter spatial resolution. This resolution affords regional coverage with enough information to make landscape-scale decisions.

Importantly, the Landsat Thematic Mapper (launched 1982, 1984) and Enhanced Thematic Mapper Plus (1999) sensors all capture light reflected from Earth in various wavelength regions (including regions both visible and invisible to the human eye) that when used together are particularly

good at revealing wildland burn damage and vegetation conditions. Healthy green vegetation reflects strongly in the near infrared (Landsat TM and ETM+ band 4, $\sim 0.75\text{--}0.9\ \mu\text{m}$), while bare ground, soil, and rocks reflect strongly in the shortwave infrared (particularly Landsat TM and ETM+ band 7, $\sim 2.09\text{--}2.35\ \mu\text{m}$). By comparing the amount of reflectance measured in these two wavelength regions before and after a fire event, data analysts can define the extent and severity of fires. This analysis method has proven to perform consistently across the range of biophysical settings found throughout the United States.

In the world of wildland management, good decisions must be buttressed by good information. Landsat supplies needed historic and current information in a consistent format at a spatial scale useful for land managers. In essence, it takes a blindfold off of land managers trying to plan for and after wildland fires, by giving them a landscape-scale overview of vegetation, soil, fuel, and burn conditions.

Following the Cerro Grande Fire, Landsat data have become essential for three inter-agency national fire-related programs: LANDFIRE, the Burned Area Emergency Response program, and the Monitoring Trends in Burn Severity project.

LANDFIRE

The interagency LANDFIRE, or the Landscape Fire and Resource Management Planning Tools project, was a direct outcome of the National Fire Plan. Its prototype started in 2002, and by 2004 it was a fully chartered program. LANDFIRE characterizes the changing landscape in terms of vegetation types and fuel load; together with weather information this enables crucial fire behavior predictions to be made.

“To the fire community, LANDFIRE data is probably of most value to those in the field who are trying to predict fire behavior,” says Dr. James Vogelmann, a USGS Research Ecologist with the project.

“We have used Landsat as the basis for our land cover mapping and vegetation characterization efforts,” Vogelmann explains. Landsat data were the primary information source for the initial LANDFIRE vegetation and land cover maps, and each year land cover updates are made based on new Landsat data to keep fuel load maps current.

The scientifically credible maps produced by LANDFIRE can be layered together to help land managers across the U.S. prioritize hazardous fuel reductions, meet conservation goals, and establish resource management plans. ▶

NATURAL DISASTERS: FIRE



[Photo Information](#)
A wildfire on Trinity Ridge in the Boise National Forest, Idaho.
Credit: B. Washa, U.S. Forest Service.

A tract of Bureau of Land Management land near Ely, Nevada before and after a prescribed burn. The photos were taken on July 7, 2009 (left, by Donald Ohlen, USGS) and on June 7, 2010 (right, Stephen M. Howard, USGS.) LANDFIRE provides land managers with important information for prioritizing where prescribed burns are needed.

Burned Area Response

During the Cerro Grande Fire, large areas were burned upstream of Los Alamos. After the fire, peak runoff flows from denuded slopes were 1000 times higher than before the fire putting townspeople at risk for flash floods and landslides. Immediately following the fire, the Burned Area Emergency Response, or BAER team, made assessments about the fire's effects on vegetation and soils and came up with a plan for rehabilitation. BAER treatments included hand-applied straw mulching of 2,700 acres within the burn scar. The treatment efforts were prioritized based not only on their modeled runoff flows and impacted popula-

tion estimates, but also on the transport of contaminated sediments from the Los Alamos National Laboratory. In the three years following the fire, the Pueblo Canyon area recorded significantly elevated concentrations of plutonium-239 and -249 in their storm runoff. In the end, Forest Service post-fire treatments costs following the Cerro Grande blaze topped \$14 million.

The threat of erosion, landslides, and flooding is greatly increased after a fire because of a two-fold fire effect: (1) burned vegetation no longer anchors the soil with its roots and (2) burned soils become largely impervious, increasing runoff. This is especially dangerous in mountainous regions adjacent to developed areas where flooding

and landslides can be a major threat to human safety. BAER first responders, armed with their ground condition assessments, can target regions that need immediate attention to stem erosion and flooding and then implement remediation measures such as culvert placement, debris fence installations, reseeding, or straw mulching.

“BAER teams respond in the immediate aftermath of wildfires and are responsible for assessing burn severity and mitigating post-fire threats to life, property, water quality, and ecosystems,” explains Carl Albury, a Remote Sensing Specialist with the Forest Service’s Remote Sensing Application Center (RSAC) in Salt Lake City, Utah. ▶



Photo Information

Sunset at the Bagley Fire, four miles west of Big Bend, CA. This lightning-started wildfire was ignited on Saturday Aug. 18, 2012. Credit: U.S. Forest Service.

Opposite corner: A BAER scientist surveys a watershed in central Washington after a Sept. 2012 fire. Credit: Bob Nichols, U.S. Forest Service.

Following full-page photo: A large smoke plume rises from the Pole Creek wildfire in the Deschutes National Forest near Bend, OR on Sept. 12, 2012. Credit: Tom Iraci, U.S. Forest Service

“These threats are predominately caused by flash floods and landslides resulting from the removal of vegetation and impaired hydrologic function of affected watersheds.”

BAER assessments and stabilization plans must be completed within seven days of a fire event. The U.S. Geological Survey’s Earth Resources Observation and Science (EROS) Center and the Forest Service RSAC teams work together to quickly get data to the BAER teams. Based on the BAER results, federal funds are requested to enable mitigation measures. Starting in 2001, EROS and RSAC began regularly incorporating Landsat satellite imagery

into their burned area mapping services.

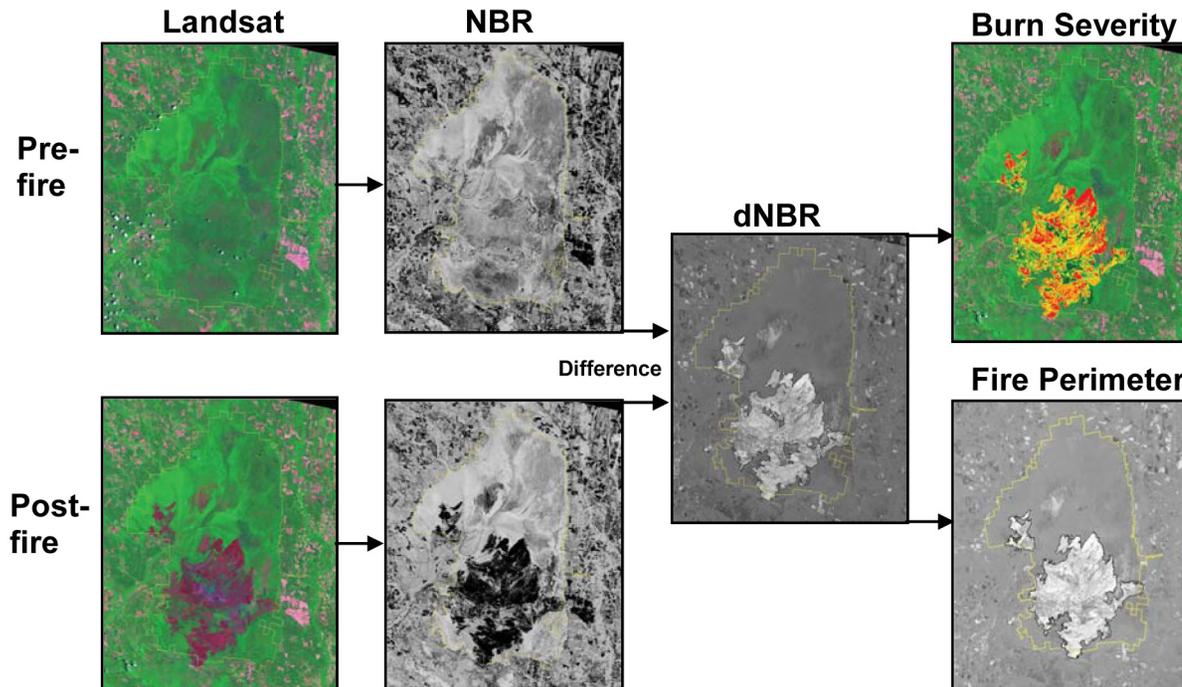
“With the large size, rugged terrain and inaccessibility of many burned areas, it can be difficult for BAER teams to assess a burned area within the seven day deadline,” Albury describes. “To expedite this process, RSAC and EROS obtains pre-fire and post-fire Landsat imagery and produces a change detection product.” This product, called a Burned Area Reflectance Classification, provides crucial information for the stabilization strategy.

“The Landsat based approach to soil burn severity mapping replaced earlier more

costly, less accurate, and less repeatable methodologies based upon the manual interpretation of burn characteristics and impacts and field sketch mapping techniques,” explains BAER support program leader and USGS Geographer Randy McKinley. Since incorporating Landsat into the BAER program, analysts have mapped over 1100 fires and 37 million acres in support of BAER teams deployed across the U.S. and occasionally to international locations.

“Historic, current and future availability of Landsat data are vital to the BAER program,” says Albury. ▶

Determining Burn Severity and Fire Perimeters with Landsat



This graphic shows the steps used to map burn severity and delineate a fire perimeter using Landsat. NBR is the Normalized Burn Ratio (Landsat Band 4 – Band 7) / (Band 4 + Band 7); dNBR is the Differenced Normalized Burn Ratio. In the Post-fire image, the fire scar is magenta. In the Burn Severity image, red shows areas of most severe damage. This fire occurred in the Okefenokee National Wildlife Refuge on the Georgia/Florida border. Image credit: Eidenshink et al., 2007

NATURAL DISASTERS: FIRE

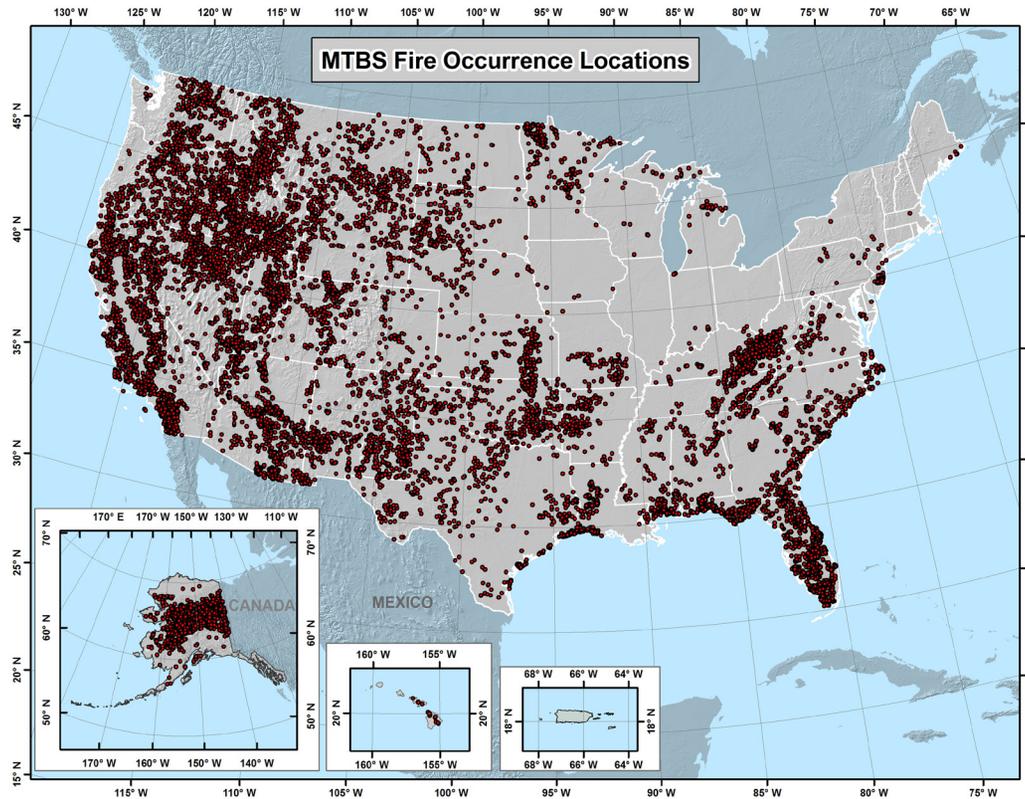


Monitoring Trends in Burn Severity

In 2004, the General Accounting Office recommended that a nationwide comprehensive assessment of fire burn severity be conducted to help monitor fire trends and to determine the efficacy of the National Fire Plan. Soon after, the governing wildland fire council initiated a corresponding program to determine the environmental implications of large wildland fires and to track trends in the burn severity of U.S. wildland fires.

To tackle such large questions, managers again turned to Landsat because of its ability to provide consistent and historic information for the entire U.S. The resulting Monitoring Trends in Burn Severity (MTBS) project has used Landsat to map all fire extents and severity from 1984 through the present for fires larger than 1000 acres in the west and 500 acres in the east. The MTBS project—another RSAC and EROS collaboration—mapped 14,945 fires that occurred between 1984 and 2010 using over 10,000 unique Landsat images. Analysis of this massive archive of information is currently underway to answer those expansive original questions put forth by the Wildland Fire Leadership Council.

The MTBS project has been extended beyond its initial 1984–2010 period



Location map of the 14,945 U.S. fires occurring 1984–2010 mapped by the Monitoring Trends in Burn Severity project (MTBS). Credit: MTBS.

and annual updates now regularly occur. Additionally, MTBS fire disturbance data is fed into the annual LANDFIRE updates providing important fuel load revisions each year, and places like the Grand Canyon National Park use MTBS information to make decisions on tactical fire management and suppression.

Better Prepared

Fire, Landsat proved to be a comprehensive data source pivotal to interagency efforts to better manage wildland fires.

“Landsat provides the ‘view from above’ and an ideal combination of resolution and spatial coverage that shows severely burned ▶

“Historic, current and future availability of Landsat data
are vital to the BAER program” —Carl Albury



NATURAL DISASTERS: FIRE

areas and resources at risk in the proper spatial context so priorities can be determined and the proper mitigation measures implemented,” says Stephen Howard, a USGS scientist with the MTBS team.

With Landsat 5’s TM sensor recently retired after 27 years of service, and the 13 year-old Landsat 7 ETM+ sensor working at a reduced (75%) capacity, the fire and fuel mapping teams for LANDFIRE, BAER, and MTBS are all eagerly awaiting the launch of the next Landsat satellite, the Landsat Data Continuity Mission (LDCM).

“The every eight day repeat coverage originally provided by the Landsat 5 and Landsat 7 satellites was very timely for BAER team reporting requirements,” McKinley says. “The loss of the Landsat 5 satellite’s Thematic Mapper (TM) instrument in late 2011 was a severe blow to BAER and related mapping programs.” In 2012, with wildfire coverage reduced to every 16 days with Landsat 7’s ETM+, BAER mapping specialists were unable to provide timely soil burn products to a number of BAER teams on the ground.

In a statement echoed by all three projects, Albury says, “We very much look forward to a successful launch and commissioning of LDCM.” ■

Meet Carl Albury, Remote Sensing Specialist with the BAER team



Carl Albury
GIS/Remote Sensing Specialist
Burned Area Emergency Response
Imagery Support Program
Remote Sensing Applications Center
Salt Lake City, Utah

Growing up, Carl Albury was an avid reader with a penchant for Jack London adventures. Albury didn’t have a clear future career vision, but he was fairly certain that he’d end up in the natural sciences. He took a job with a surveying company as a teen and began his journey measuring and assessing the physical world around him. He majored in Geology at the University of South Florida and went on there to earn a Master’s degree focusing on hydrogeol-

ogy and requiring a fair amount of field research. Albury’s first post-graduate job was assessing and remediating groundwater contamination. From there he migrated into water resources and started using aerial photography and satellite imagery—including Landsat—to assess environmental conditions.

“When I had an unexpected opportunity to get into the fire mapping world, I jumped on it,” Albury says. In 2011, he took a job as a contractor with the Forest Service’s Remote Sensing Application Center in Salt Lake City, Utah and today Albury manages the BAER imagery support program there.

“My diverse background and firm foundation in the earth sciences helps me understand both the modeling that we perform and the implications of translating the results of those models to action on the ground,” Albury shares. “The work I perform here provides real, tangible help to the BAER teams who are in turn taking action to protect human life, property, and natural resources. I find the fact that my work has an immediate and positive impact on people’s lives very meaningful.”

Satellite Data Requirements:



8-day revisit (w/ L7)



≤ 30 m resolution



Vis, NIR, SWIR, TIR



continuous spatial coverage



archive continuity & consistency



rapid delivery of free, unrestricted data



geolocation ≤ 0.5 pix



≤ 5% radiance calibration



8-bit data digitization

See inside back cover for more information



Handwritten blue scribble, possibly initials or a signature.





The Maryland and Virginia suburbs of Washington, DC experienced rapid growth between 1984 (left) and 2011 (right). The most dramatic growth is near Dulles International Airport, image left. Bright white patches are clouds.

Opposite: Landsat provides the longest space-based record of Earth's landscapes in existence, making it possible to track change since 1972.



Effective Tools for Cleaning Our Waterways | Jeannette Allen

Pam Anderson and her colleagues at the Minnesota Pollution Control Agency's Lakes and Streams Monitoring Unit have an unusually big job. Popularly known as the Land of 10,000 Lakes and home to more than 12,000 of them, Minnesota has vast water resources, and Anderson and her colleagues are responsible for monitoring, managing, and protecting all of them. It would be an impossible task if not for satellite data, including a Landsat-based map of land use.

The Clean Water Act requires states to adopt standards for how much biological, chemical and physical pollutants (bacteria, nutrients, biosolids, oil, etc.) can be in the water and still be safely used for drinking, fishing, and swimming. States are responsible for implementing and enforcing these federal laws. Every two years, states must assess the health of their waters, determine which ones are not meeting water quality standards, and report on them to the Environmental Protection Agency. Bodies of water that fail to meet the standards automatically go on the EPA's list of impaired waters and are tagged for further study, monitoring, and restoration. Once water quality standards are restored in a body of water, it is removed from the impaired list.

States do their best, "but the impaired list keeps growing," says Jim Wickham,

Senior Research Biologist with the Environmental Protection Agency. "It's easier to measure and report on water quality than to bring impaired waters back to health. Something on the order of 50,000 water bodies are currently impaired, roughly 1,000 per state."

In Minnesota, nearly 40 percent of the state's waters are listed as impaired, a rate comparable to what other states are finding. Anderson and others at the

Minnesota Pollution Control Agency are hard at work to assess its waters, to preserve the health of those that are clean, and to restore those that are impaired.

"Where water sampling tells us the waters are impaired and not meeting the national and state standards, we have to determine why," says Anderson. "What is impairing the waters, stressing the fish? Is it land use change such as loss of forest to development? Is it low oxygen levels?" ▶



[Photo information](#)
Opposite: The Minnesota Pollution Control Agency monitors waterways such as Wolf Creek in Banning State Park so that drinking water remains clean for people downstream (below). Credit: (above) stta, (below), kuppaa. Above: Land use, including farming, impacts water quality. Credit: dobak on flickr.com.



5 miles



[Image information](#)

Landsat 5 acquired this image of northeastern Minnesota on October 10, 2011. Clear water is black, since sediment reflects light, making the water appear green. Land cover affects water quality. Forest is dark green, cities are gray, and bare earth is tan. The brown area is land recently burned in a wildfire. Credit: NASA's Earth Observatory

The National Land Cover Data Base

She and others have found that a profound influence on the life of waterways and their health is what happens on the lands surrounding them. Urbanization, farming, timbering, wild fires, or wetland removal impact water quality by adding chemical pollutants or physically altering the flow of water. For example, urbanization can increase municipal sludge production and facilitate movement of pollutants into waterways. Farmers apply fertilizers and pesticides to croplands, and rains and drainage systems can transport these to local water supplies. Livestock manure contains nitrogen and phosphorus that may also contaminate water supplies.

“We have to look at land use and determine whether or not it is a factor in impairment of the waters. In a big state with a lot of waters, that’s a demanding job,” says Anderson. In fact, the job would be nearly impossible without the view from Landsat satellites. Since 1972 the series of Earth-observing Landsat satellites have observed and measured changes in the world’s land cover and land use consistently, reliably, and accurately. These observations have been compiled into a large database, called the National Land Cover Database,

used by states to help them to characterize and quantify changes on the land and so comply with the Clean Water Act.

“Land cover and impervious cover are very critical to implementing the Clean Water Act, and the National Land Cover Database is the backbone of this process,” explains Anderson, “Because we have the National Land Cover Database, we can look region by region, watershed by watershed, at our state, and how land use is impacting our waters.”

Tom Pearson, Research Analyst in the Watershed Division, explains further how watershed assessment for water quality in Minnesota works. “We study watersheds that average 1,000 square miles. They’re big. We need the National Land Cover Database to give us the big picture of land use. Using Geographic Information Systems (GIS), we combine the land cover data with four other datasets for each watershed: riparian zone conditions; number of feedlots and feedlot animal density; surface water discharges; and the degree of channelization in streams. Out of that we generate a Human Disturbance Score for each of the 45-50 subwatersheds in the larger watershed. This helps us to focus our resources and to get the most water quality improvement out of the work we do.”

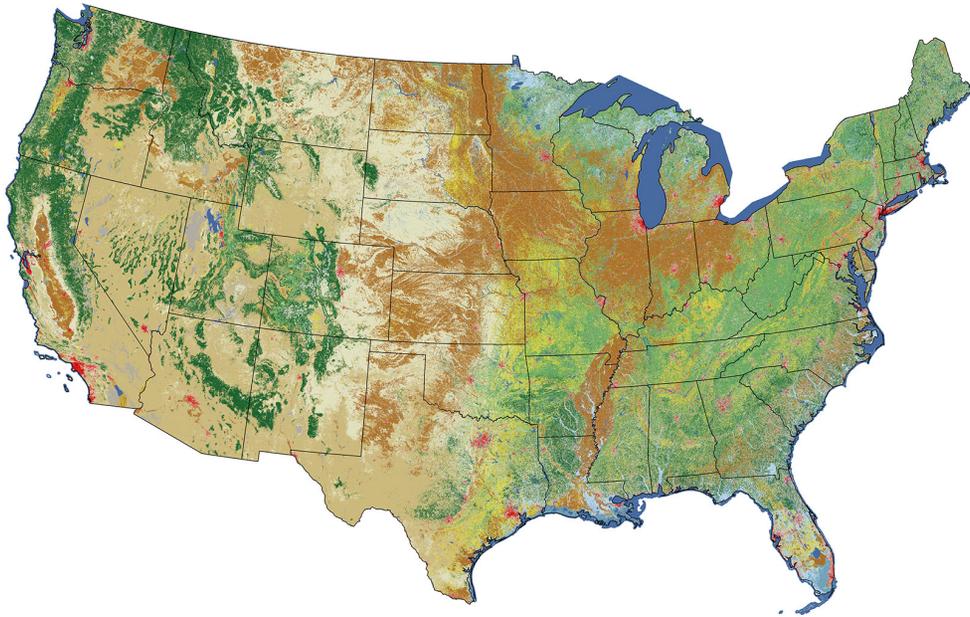
“We need to be able to address both point and non-point sources of pollution,” continues Pearson. “Non-point sources can be elusive and challenging to identify. The National Land Cover Database gives us the land use data we need to help identify non-point pollution sources that are often a very important part of the overall water quality picture.”

Restoring Waterways

On the national level, Wickham fully expects use of the National Land Cover Database for state level water quality assessments to spread partly because of recent developments at the EPA. The Clean Water Act did not provide guidance on how states might strategically approach making improvements to their waterways’ health. “In the beginning states tended to try cleaning up the most impaired waters, using the ‘worst first’ approach,” he explains. “That’s often a failure because some waters cannot be cleaned up!” The EPA developed a step-by-step how-to process for states to analyze their waterways and to determine the most likely ones to be brought back to health.

The guidelines contain multiple indicators that states can use to assess potential recovery, including the structure of the ▶

LAND USE AND LAND COVER CHANGE



The National Land Cover Database is a 16-class land cover classification scheme using a spatial resolution of 30 meters. What covers the surface of the land (such as forest, farmland, or urban areas) and how people manage their lands has profound influences on water quality and so affects human health. The Minnesota Pollution Control Agency uses the National Land Cover Database in multiple critically important ways to strategically implement federal and state water quality laws.

waterway, stability of shore lands, water flow and channel dynamics, integrity of the biological communities, ecological history, and several more traits of the waterway. Many of those indicators are developed from the National Land Cover Database.

Back in Minnesota, the National Land

Cover Database has already helped to keep the list of impaired waters from lengthening. North Tamarack Lake is a large 3,520 acre shallow lake located in the northwestern part of the state. Anderson notes, “North Tamarack Lake tripped our threshold for impairment. But it’s set in a natural background surrounding by Tamarac

National Wildlife Refuge, and land use is very well intact.” This meant that human activities had not harmed the lake. “Our understanding of the land use around it kept that lake off the impaired list.”

Preventing Pollution with Land Use Decisions

Beyond helping authorities to understand the impacts that landscapes have on the life of specific waterways, the National Land Cover Database is an important component of models used to predict water quality. “We are a regulatory agency and we need to understand the effects of point source pollution for permitting purposes,” says Charles Regan, hydrologist and lead modeler for the Technical Assistance Unit in the Watershed Division of Minnesota’s Pollution Control Agency. “The National Land Cover Database is a critical data source in the models I use to make hourly estimates on dissolved oxygen, phosphorus, and nitrate amounts to measure against our water quality standards. We sample the water itself only 20 to 40 days per year, and the National Land Cover Database helps us to fill in the gaps.”

“The National Land Cover Database is an integral part of our toolbox. Minnesota does not have any other way to get this kind of current data,” remarks Anderson. ▶



[Photo Information](#)
Above: The Mississippi River flows through brightly-lit Minneapolis. Urban landscapes must be carefully managed so that municipal sludge and pollutants are kept from waterways, allowing the water moving through them to remain healthy for people and ecosystems. Following full page photo: U.S. Geological Survey scientists collect a sample from the Knife River in Minnesota. Water quality field samples are tested for bacteria, turbidity, nutrients such as nitrogen and phosphorus, and specific pollutants such as mercury. Credit: U.S. Geological Survey.



“The National Land Cover Database gives us the land use data we need to help identify non-point pollution sources that are often a very important part of the overall water quality picture.” —Tom Pearson

LAND USE AND LAND COVER CHANGE

Learn More:

Land Use Impacts on Water
<http://www.epa.gov/greenkit/toolwq.htm>

Multi-resolution Land Characteristics Consortium
<http://www.mrlc.gov/finddata.php>

National Land Cover Database 2006
http://www.mrlc.gov/nlcd06_data.php

Recovery Potential Screening, EPA
<http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/index.cfm>

Testing the Waters: Using Satellites to Monitor Lake Water Quality
http://earthobservatory.nasa.gov/Features/WaterQuality/water_quality.php ■

Meet Thomas Pearson, Research Analyst with the Minnesota Pollution Control Agency



Thomas Pearson
Research Analyst
Watershed Division,
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Saint Paul, Minnesota

I learned to love the natural world when I was a boy, swimming and sailing in the Atlantic Ocean off the Rhode Island coast, and then hiking, canoeing, and swimming in the lakes and rivers of New Hampshire and Maine. I loved working as a camp counselor too, helping kids explore the outdoors, learn new skills, and develop confidence in their abilities.

In eighth grade I did a laboratory experiment in freshwater population ecology with snails and aquatic plants. The experiment clearly showed the results of overpopulation of animals in finite ecosystems, and the problematic effects this can have on water quality. The results of that eighth grade experience

stay with me as a reminder of the importance of balance in natural systems.

I studied at the University of Wisconsin-Madison. Internships and early jobs with the Bureau of Land Management, the U.S. Geological Survey, the Environmental Protection Agency, and the National Oceanic and Atmospheric Administration helped me to build my skills and connections in the geospatial and environmental fields, which seemed to have strong potential for growth.

Working in water quality, remote sensing, and Geographic Information Systems for the Minnesota Pollution Control Agency allows me to combine interests in people/environment studies, environmental science, computer science, and graphic design. I like that diversity. I also feel that we have a very important mission because water is such a critical resource for life on the planet.

I encourage young people to find what they feel interest and passion for, and to balance that with finding a way to pursue those interests while making a living in the world. Finding a way to be useful, to make a contribution to something important, and to put one's strengths and skills to good use is a great foundation for a happy and fulfilling life.

Satellite Data Requirements:



16-day revisit (8-day revisit desired)



30 m resolution



Vis, NIR, SWIR, TIR



Global coverage



archive continuity & consistency



rapid delivery of free, unrestricted data



geolocation ≥ 15 m

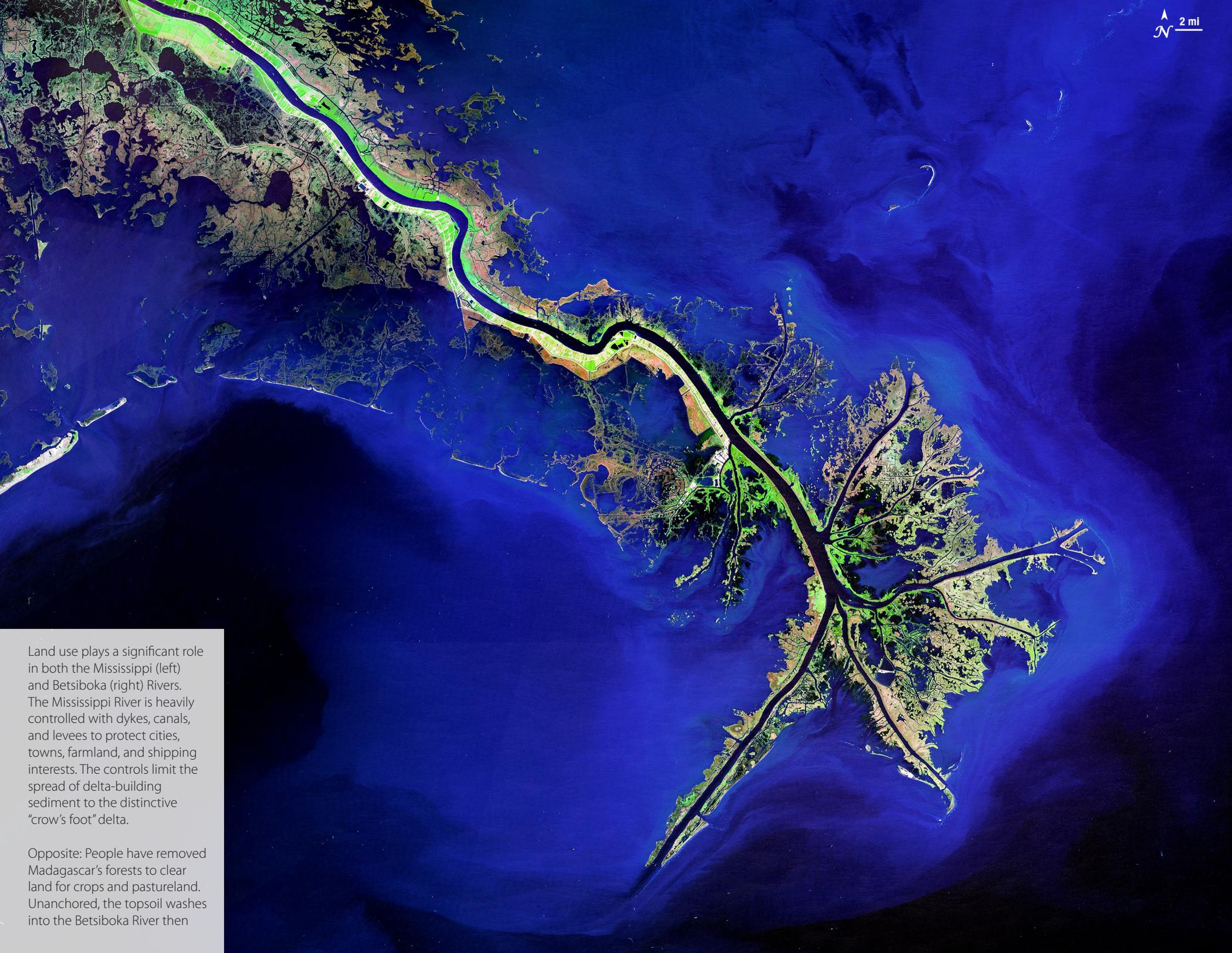


Calibration $\geq 5\%$



≥ 11 -bit data digitization

See inside back cover for more information



Land use plays a significant role in both the Mississippi (left) and Betsiboka (right) Rivers. The Mississippi River is heavily controlled with dykes, canals, and levees to protect cities, towns, farmland, and shipping interests. The controls limit the spread of delta-building sediment to the distinctive "crow's foot" delta.

Opposite: People have removed Madagascar's forests to clear land for crops and pastureland. Unanchored, the topsoil washes into the Betsiboka River then





WATER

Mapping Water Use

Holli Riebeck and Laura Rocchio

Dean Stevenson has farmed the plains of south-central Idaho most of his forty-seven years. Like all farmers, he worries about things like the price of sugar beets and malt barley or the cost of gasoline, but most of all, he worries about water.

He is right to worry. The 4,000 acres he farms with his father and brother receive on average a scant 10 inches of rain per year. The water that sustains the sugar beets, barley, wheat, and potatoes growing on Stevenson land is pumped from the Snake River Plain aquifer. Every drop is rationed.

In 2006, the staff of another irrigation district on the Snake River Plain, A&B, believed that some of its farms had run short on water, resulting in a poor harvest. Because A&B has senior (older) water rights, Idaho law allowed the irrigation district staff to issue a water call, a demand that junior water right holders, including Stevenson, draw less water from the aquifer.

The agency with the unenviable task of sorting out water calls is the Idaho Department of Water Resources. The agency keeps track of how much water is in the state's rivers and ground water to ensure that Idaho has a viable water supply for all of its users—farmers, cities and towns, and natural ecosystems.

State water agencies across the western United States face similar challenges. “Chronic water supply problems in many

areas of the West are among the greatest challenges we face in the coming decades.” Mark Limbaugh, the U.S. ▶



[Photo information](#)
Opposite: Annual rainfall along Idaho's Snake River Plain is as low as 10 inches (2.5 centimeters) per year, or less, isn't enough to support crops in the region. Credit: p.m. graham on flickr.com. Below: Many western farmers rely on irrigation. Credit: Robert Burns, USDA. Above: Pivot irrigation gives these Colorado fields a circular shape. Credit: USDA.



[Image information](#)

The Snake River winds through native scrub vegetation and geometric agricultural fields in this image taken on September 25, 2010, by the Advanced Land Imager on NASA's EO-1 satellite. The Advanced Land Imager was a prototype for the Operational Land Imager on the Landsat Data Continuity Mission (Landsat 8). Credit: NASA Earth Observatory

Department of the Interior's (DOI) former Assistant Secretary for Water and Science, told U.S. Senators in 2006.

The challenge in refereeing water disputes, or managing a water supply in general, has always been figuring out how much water is actually being used. Most of us think of 'water use' as the water we are billed for every month. But for state water managers, 'water use' has a different meaning. They consider water to be used when it evaporates from the ground or is soaked up by growing plants and released (transpired) as water vapor through openings (stomata) found on the undersides of leaves.

A water meter, such as those on the wells that Dean Stevenson uses to pump irrigation water from the Snake River Plain aquifer, tracks how much water a user withdraws, but not how much is actually consumed or used. To track farmers' water use, the Department of Water Resources needs to measure evapotranspiration (evaporation plus transpiration) across millions of acres of cropland—a nearly insurmountable task. Idaho uses more water than any other U.S. state except California and Texas, and more than 90 percent of the water consumed in Idaho goes to irrigate 3.4 million acres of farmland, providing the economic base for the state.

Enter Landsat

"Remote sensing was the only way to throw a rope around all the water consumption going on in Idaho," says Rick Allen, a water resources engineer at the University of Idaho. With a grant from NASA in 2000, Allen and Tony Morse, the Department of Water Resources geospatial technology manager (recently retired) began looking for ways to use data from the Landsat satellites to estimate evapotranspiration (ET) across the Snake River Plain and other farmland in Idaho.

Detailed water consumption maps can be made quickly and easily with Landsat because of its 30 m spatial resolution and thermal imaging capability. Landsat has been proclaimed "the best and least expensive way to quantify and locate where water is used and in what quantity," by Morse and Allen.

The Landsat-based estimates of water use come from a model called METRIC, for "Mapping Evapotranspiration at high Resolution with Internalized Calibration." By 2003 METRIC was beginning to run as an operational model at the Idaho Department of Water Resources.

The Landsat satellites have a number of characteristics that make them well suited for water-use mapping:

(1) The spatial resolution of Landsat enables water managers to map water use for individual agricultural fields and thereby manage on a field-by-field basis. With coarser-resolution data this doesn't work. Landsat's resolution "helps us to resolve water consumption on the scales of anthropogenic interaction and land and water ownership," Allen explains.

(2) Landsat's spectral coverage includes a thermal infrared band. This thermal information is essential for water-use mapping because the mapping process is predicated on the fundamental principle that evaporating water consumes energy, i.e. the more water fields are losing through ET, the cooler they are.

(3) There is now an archive containing more than a quarter of a century worth of global Landsat data that has the spatial resolution, spectral coverage, and thermal imagery needed for water-use mapping. "Landsat provides continuity to assess change in ET over time and to document historical water consumption," Allen says—an essential capability in the U.S. West, where water rights often are established by historical precedence.

(4) The Landsat satellites' orbit place them overhead during morning hours, avoiding common afternoon cloud cover. ▶

WATER

(5) The entire Landsat archive is publicly available at no cost. As Morse highlights, “all parties to a water dispute have equal access to a primary data source.”

The METRIC Model

Prior to using METRIC, the Idaho Department of Water Resources estimated evapotranspiration for each county from temperature, humidity, wind speeds, and sunlight measured at regional weather stations coupled with thousands of less-than-dependable water meters. For the eastern Snake River Plain in Idaho, this type of traditional monitoring cost the state half a million dollars per year. In comparison, the same monitoring done with Landsat data is \$80,000. When looking at the western states together, Morse has estimated a potential ten-year savings as high as \$1 billion

When the A&B water call came in to the Department of Water Resources, Morse and Bill Kramber, a remote sensing analyst, had just started to analyze water use throughout the state during 2006.

To determine if farmers in the A&B district had been damaged by water shortages, all Kramber and his colleagues had to do was compare water use, which they got from evapotranspiration determined by METRIC, to vegetation ▶

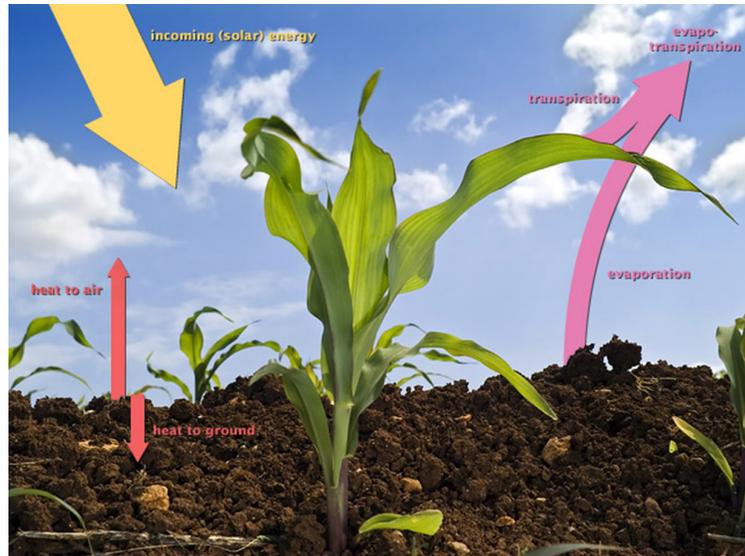


Photo Information
Above: Irrigated farms in southern Idaho use water from both the Snake River and the Snake River Plain aquifer. Credit: j o s h on flickr.com

Incoming sunlight either heats the ground and the overlying air, or it drives evapotranspiration—the evaporation of water from the ground or the leaves of plants. Scientists infer water loss from the amount of energy being consumed by evapotranspiration. (Corn Image ©2010 Noam Armonn. Used under license from Shutterstock.com. Diagram by Robert Simmon, NASA’s Earth Observatory.)



Photo Information

Above: Instrument stations measure evapotranspiration and atmospheric moisture for a single location. Landsat provides a less detailed, but broader perspective. Credit USDA. Opposite corner: Monitoring agricultural water use ensures that water resources are available for other uses, including recreation. Credit: woodley wonderworks on flickr.com. Following full-page photo: A mustard crop grows in the hills near Moscow, Idaho. Credit: Bob Nichols, USDA.

growth, which can also be assessed using Landsat data. They compared these measurements for the A&B district to those of surrounding farms that relied on both ground water and surface water.

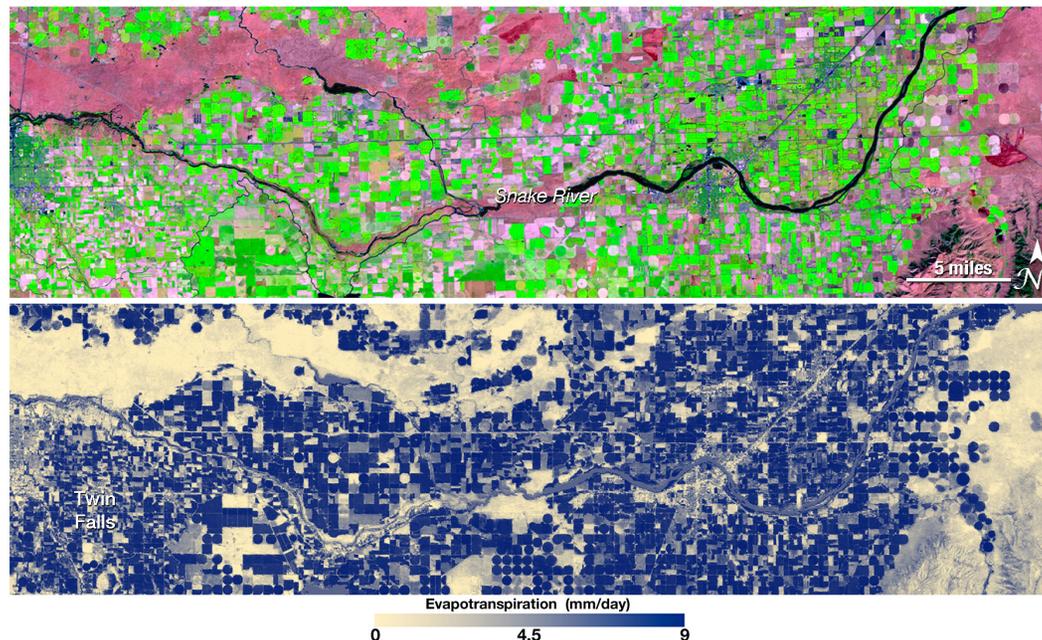
“It just didn’t look like the area was any different than the surrounding areas. If it had been short of water, it should have shown a lower evapotranspiration rate,” says Kramber.

The director of the Idaho Department of Water Resources decided there simply wasn’t enough evidence that A&B farmers had suffered substantially as a result of water shortages. Their fields seemed to be as productive as anyone else’s. The director denied the water call, deciding not to curtail Stevenson and other ground water irrigators in his district. A&B appealed the decision, bringing METRIC into the Idaho court system.

Improving Water Use

With his water rights upheld for now, Stevenson sees applications for METRIC outside the courtroom. He sees it as a tool that could save money by helping him assess how much water he is actually using. It costs money to pump water from the aquifer, and he wants to pump only what he actually needs. “Water is a finite resource, and whatever we can do to try to maximize and optimize the use of that resource is a good ▶

Vegetation, Temperature and Evapotranspiration



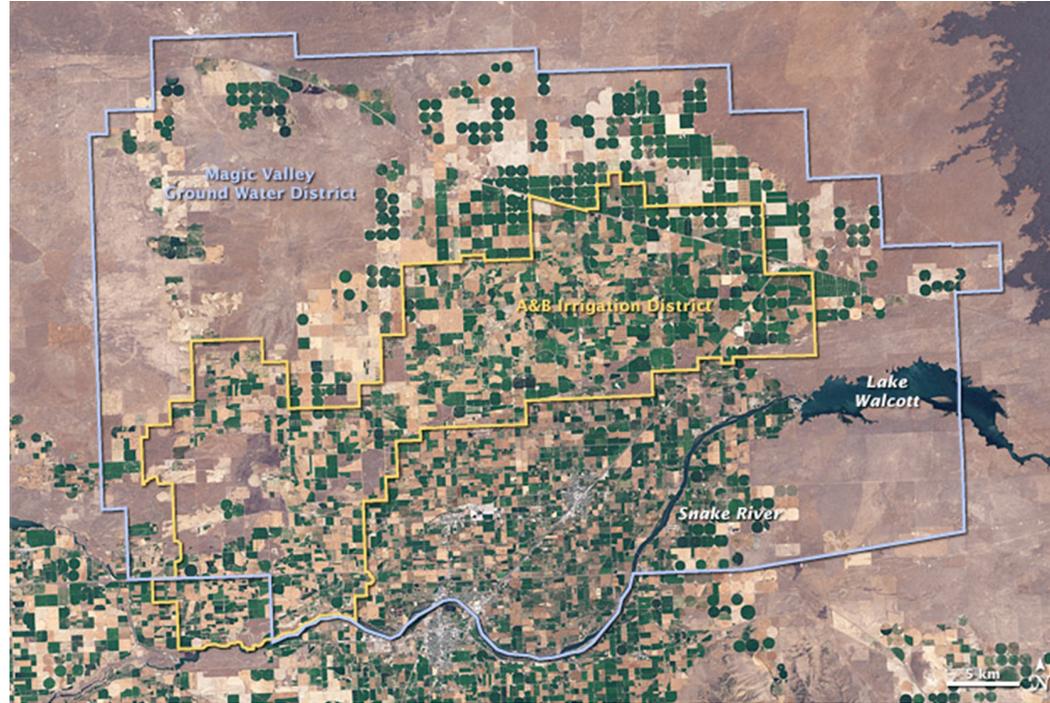
Scientists use Landsat measurements of infrared and visible light reflected from vegetation (top) to determine how much plants are growing and how hot the surface temperature is. In this infrared and visible image, crops are various shades of green, while bare or sparsely vegetated ground is pink. Such measurements are used to calculate evapotranspiration rates and to estimate water use (below). The most heavily vegetated areas are usually cool because the energy from sunlight goes into converting liquid water to water vapor, instead of heating.

WATER

thing for us. Whatever we can do to get better information on what [water] we use, we as producers will benefit from that,” he says.

A large number of winners are western water managers, who now have an efficient way to monitor and manage water consumption. In the dry Western states, irrigated agriculture accounts for 86% of all water consumption, and the water-use information provided by METRIC is critical for arbitrating increasingly common water-resource conflicts. As agricultural irrigation needs, swelling city populations, and a changing climate increase demand for scarce water supplies, water management strategy is shifting from increasing water supply to innovatively managing water use at sustainable levels. Accurate water-use mapping is essential for effective water management, and the Landsat-based method can be as much as 30 percent more accurate than traditional measurement methods.

In the decade since Idaho introduced METRIC, users in many thirsty Western states have adopted it. These states include California, Colorado, Montana, Nebraska, Nevada, New Mexico, Oregon, Texas, Utah, and Wyoming. The mapping method has enabled water managers in these states to negotiate Native American water rights; ▶



The Idaho Department of Water Resources used Landsat evapotranspiration data to determine that crops in A&B had been getting about the same amount of water as surrounding crops. This Landsat-7 image shows the region on August 1, 2001, with water district boundaries from the Idaho Department of Water Resources. Credit: NASA Earth Observatory.



“Remote sensing was the only way to throw a rope around all the water consumption going on in Idaho.” —Rick Allen



WATER

assess urban water transfers; manage aquifer depletion, monitor water right compliance; and protect endangered species.

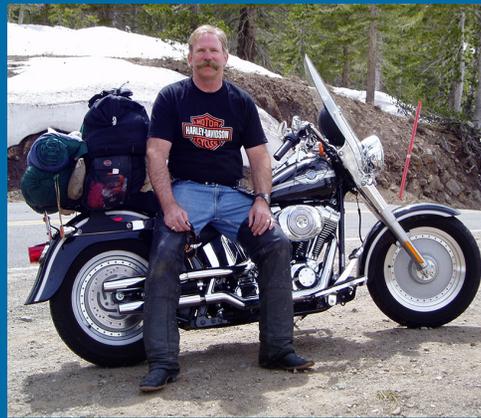
Learn More:

NASA Earth Observatory's Water Watchers
<http://earthobservatory.nasa.gov/Features/WaterWatchers/>

Precious Resources: Water & Landsat's Thermal Band
http://landsat.gsfc.nasa.gov/news/news-archive/soc_0011.html

Landsat-based Water Use Mapping Method Hailed as an Important American Government Innovation at
http://landsat.gsfc.nasa.gov/news/news-archive/soc_0021.html ■

Meet Rick Allen, Professor of Water Resources at University of Idaho



Rick Allen
Professor of Water Resources
University of Idaho
Moscow, Idaho

One way or the other, I've almost always worked. I toiled on my father's farm from 6 am to 7:30 am each day before school and again from 4 pm to 8 pm each night, and Saturdays and some Sundays. I fed pigs and cattle, shoveled manure, ran machinery in corn and soybean fields, and pulled weeds. But I knew I had to leave the family farm because I wanted to explore.

I got an Agricultural Engineering degree from Iowa State University, where several professors shared with me their passion and skills for bringing technology to

people. They taught me how to develop creative, practical ideas and to put them boldly into practice to help solve problems for others. At that time I also discovered more of nature, an abiding love for riding motorcycles, and good books.

I continued to follow the allure and intrigue of learning, increasing my understanding of physics and the physical world and my ability to develop tools to quantify and manage it. I got a MS and then a Ph.D degree. Famines in Africa continually caught my attention, and I felt compelled to join the battle to meet people's resource and food needs. So I did some work in developing countries teaching irrigation and research technology.

Now I am a Professor of Water Resources Engineering at the University of Idaho, a member of the Landsat Science Team, and a consulting engineer. I visualize solutions to technical problems, and then to solve them I develop new mathematical relationships and computer programming codes. For fun sometimes I fire up my 1961 International 560 diesel tractor just to hear the motor cackle. I drag race semitrailers on my Harley motorcycle too. I give them a one-eighth-mile head start at 60 mph in a three-eighths-mile race. I love winning but it's the race itself that I love most!

Satellite Data Requirements:



16-day revisit



30 m resolution



Vis, NIR, SWIR, TIR



Global spatial coverage



archive continuity & consistency



rapid delivery of free, unrestricted data



geolocation \geq 15 m

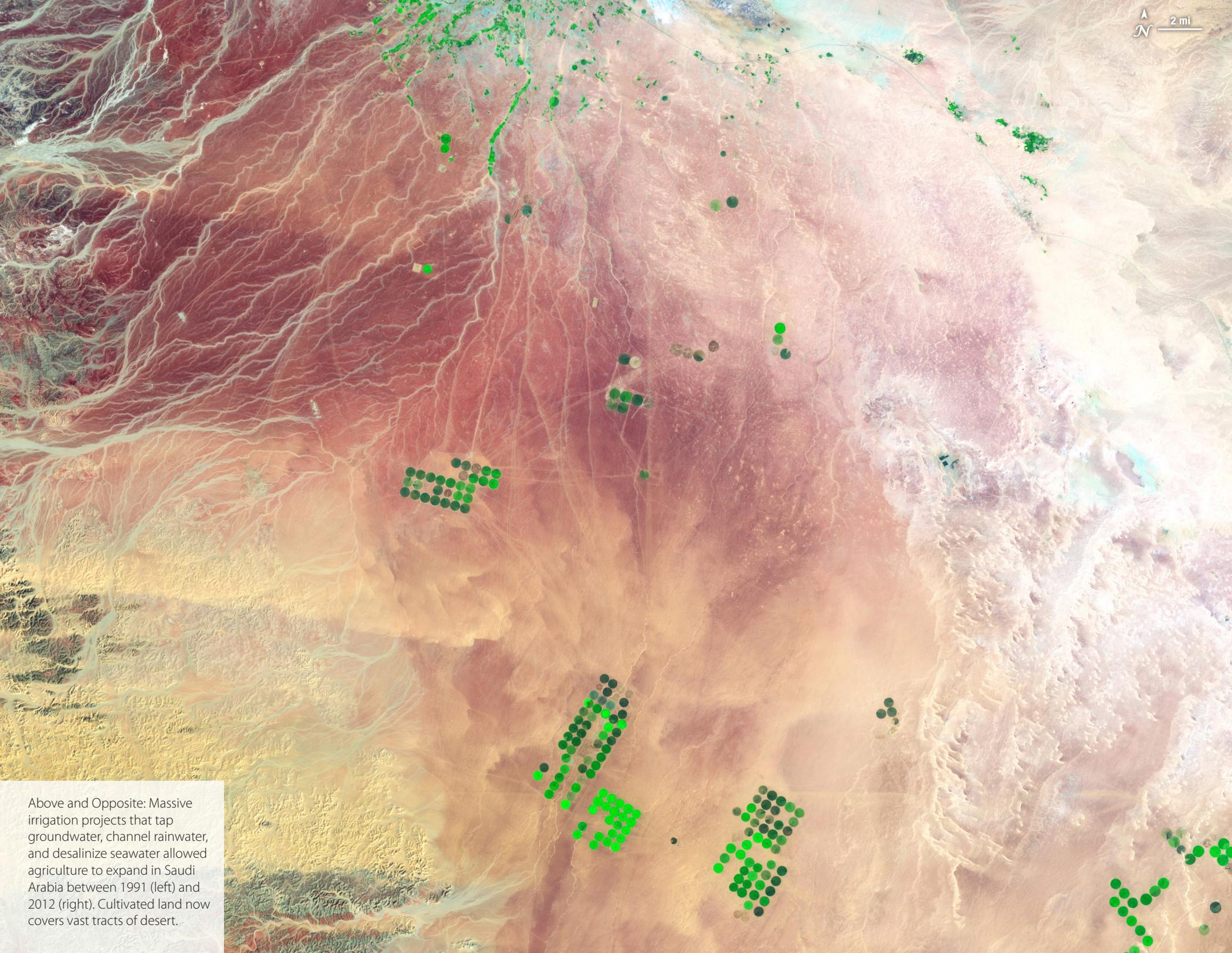


Calibration \geq 5%

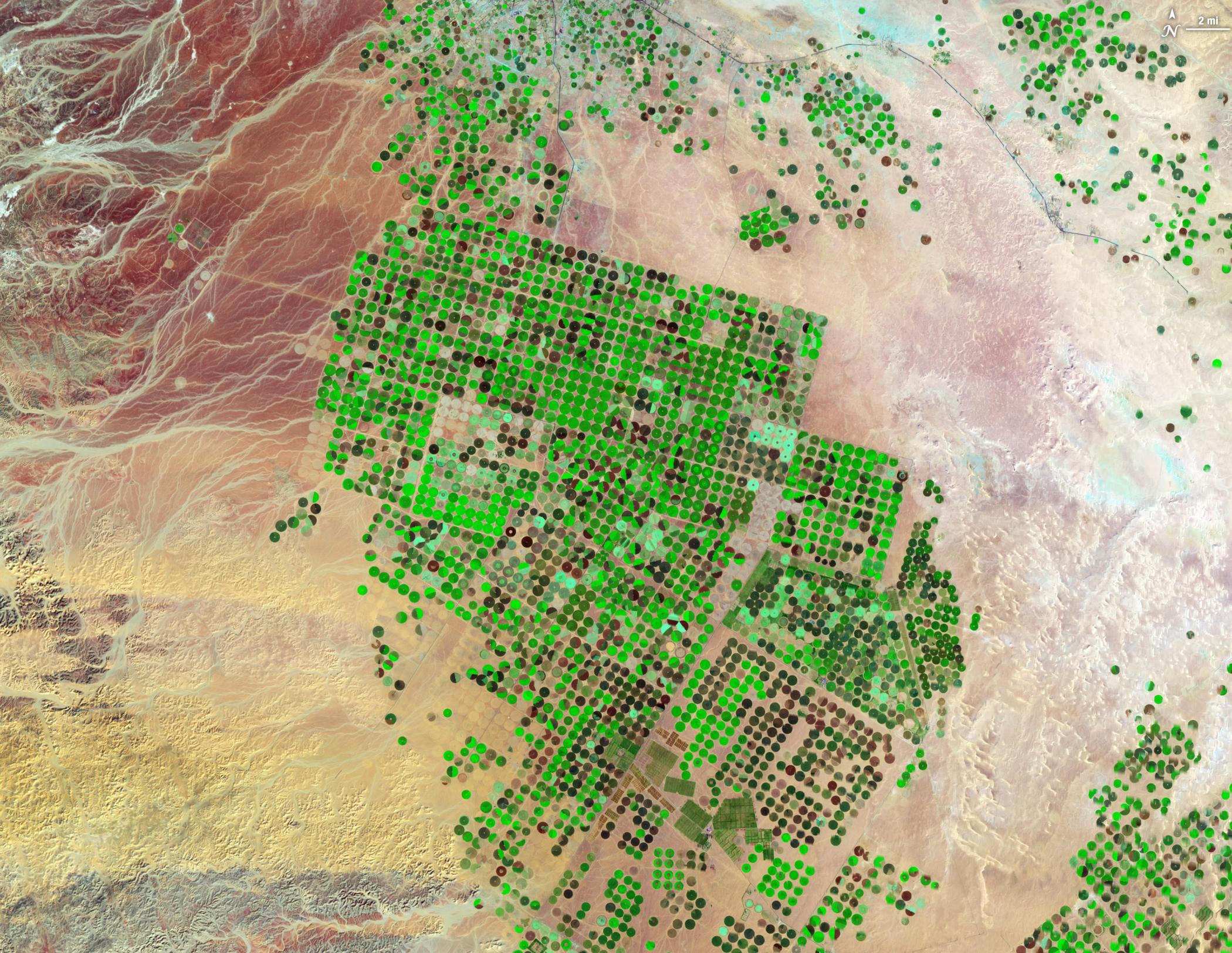


12-bit data digitization

See inside back cover for more information



Above and Opposite: Massive irrigation projects that tap groundwater, channel rainwater, and desalinate seawater allowed agriculture to expand in Saudi Arabia between 1991 (left) and 2012 (right). Cultivated land now covers vast tracts of desert.





Monitoring Crops from Space: A Decades-Long Partnership

Holli Riebeek

From George Washington to Abraham Lincoln, early U.S. presidents struggled to determine the value and extent of U.S. agriculture—then the country’s primary economic engine. Despite Washington’s best efforts, the U.S. did not have an annual agricultural survey until Abraham Lincoln established the Department of Agriculture in 1862. In the Department’s first agricultural status report, issued on July 10, 1863, chief statistician Isaac Newton explained the need for crop information:

“Ignorance of the state of our crops invariably leads to speculation, in which oftentimes, the farmer does not obtain just prices...and the consumer is not benefited.” (Quoted in *The Story of U.S. Agricultural Estimates*, pg. 23)

Today, the U.S. Department of Agriculture’s National Agricultural Statistics Service (NASS) continues to publish regular crop reports to “provide objective and unbiased statistics on a pre-announced schedule that is fair and impartial to all market participants,” according to its mission statement.

“Since the agency was established in 1863, we have been mandated to determine agricultural production to feed the population and maintain food security,” says

Rick Mueller, head of the spatial analysis research division at NASS. “Today, the crop reports encourage calm in the market place and fair and equal play for all.”

From the beginning, the challenge in producing the monthly crop reports lay in collecting consistent, accurate crop figures

from farmers (who underestimated crop production in fear of higher taxes) and, later, designated county-level agriculture representatives. For this reason, NASS became an early proponent of launching a satellite to observe Earth’s land. A satellite can provide an entirely impartial accounting of crop ▶



[Photo Information](#)
Below: US farmers produce about \$100 billion in crops every year making food more affordable in the US than in any other developed country. Credits: opposite, samott; below Natalie Maynor; above, USDA.



[Image information](#)
Landsat 5 acquired this image of farms near Garden City, Kansas on August 14, 2011. Traditional rectangular fields are being overtaken by the circles formed by center-pivot irrigation.

area and health. The service formed a remote sensing branch in 1968—four years before NASA launched the nation’s first land-observing satellite, Landsat 1. In the decades since, the U.S. Department of Agriculture has been one of Landsat’s primary users.

Landsat and Agriculture

“Landsat is beneficial to NASS because it provides a mechanism to enhance the statistics. We blend information from the satellite data with survey data,” says Mueller. Using Landsat data, crop analysts can estimate the aerial extent of fields planted with corn, soybeans, hay, wheat, rice and other crops.

Landsat is useful to crop analysts because of the wavelengths of light it records and because of its resolution. The Landsat satellites measure reflected visible light just like our eyes do, but the satellites also record additional wavelengths of infrared light that people can’t see. Each crop reflects light uniquely, giving analysts the ability to differentiate crops. In addition, reflected infrared light provides information about the water content and physiological status of plants, allowing analysts to assess crop health and productivity.

Landsat’s resolution [level of detail] is also critical for crop monitoring. Like

choosing between a zoom lens and a wide-angle lens on a camera, satellites can observe the Earth in detail while seeing a narrow swath of ground, or they can see a wider area in less detail. Landsat splits the difference. Each pixel in a Landsat image shows an area about the size of a baseball diamond, 30 meters by 30 meters, and each image shows a swath of ground that is about 185 kilometers wide—a wide enough area to make regional crop monitoring feasible. This means that Landsat data can be used to estimate how large an area has been planted in specific crops.

Production, the amount of a particular crop harvested, is calculated by multiplying crop area by yield. Landsat provides area, while other satellite instruments, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Aqua and Terra satellites, can measure daily crop health, from which yield can be calculated.

USDA also uses other Landsat-like satellites to calculate area, but Landsat provides a unique historical record. “Landsat has a known predicted orbit that systematically repeats,” says Mueller. This means that a single point on the ground will be in the same place in every Landsat scene, making it possible to track change in agricultural land from year to year since 1972.

The Landsat Data Continuity Mission will continue that record into the future.

The Power of Free Data

While Landsat provides a powerful tool, it took time for NASS to use the information extensively because of the computing power required to process and composite Landsat scenes. In addition to the effort involved, Landsat data once cost several hundred dollars per scene, forcing NASS to focus their efforts on key crop-growing regions in the Midwestern United States. All of that changed in early 2009 when the United States Geological Survey, which archives and distributes Landsat data, began distributing the data free of charge.

“When the USGS announced the free data policy, that was a game changer. It allowed us to expand our monitoring program across the whole country,” says Mueller. In January 2011, NASS released CropScape, an interactive web visualization portal that shows where crops were grown in the continental US during the previous year. Based partly on Landsat data, the annual crop maps are available in select states dating back to 1997, providing an easy method to make comparisons. “Now we can provide Landsat-based crop data for the entire country to anyone anywhere in the world,” says Mueller. It is the most ▶

FOOD



Photo Information
Above: In the early 1970s, U.S. wheat farms were productive, while in Asia they failed. The Soviet Union took advantage of low prices to purchase a large amount of wheat, upsetting world markets and giving the U.S. a significant disadvantage in the price it could charge for its wheat. Immediate Left: Subsequently the USDA established a global crop surveillance and reporting system that now utilizes satellites to monitor crop production around the world and keep prices stable for consumers. Credit: Above, Grecaud Paul; Immediate Left, Amy Jeffries; Following full-page photo, Bob Nichols, USDA.

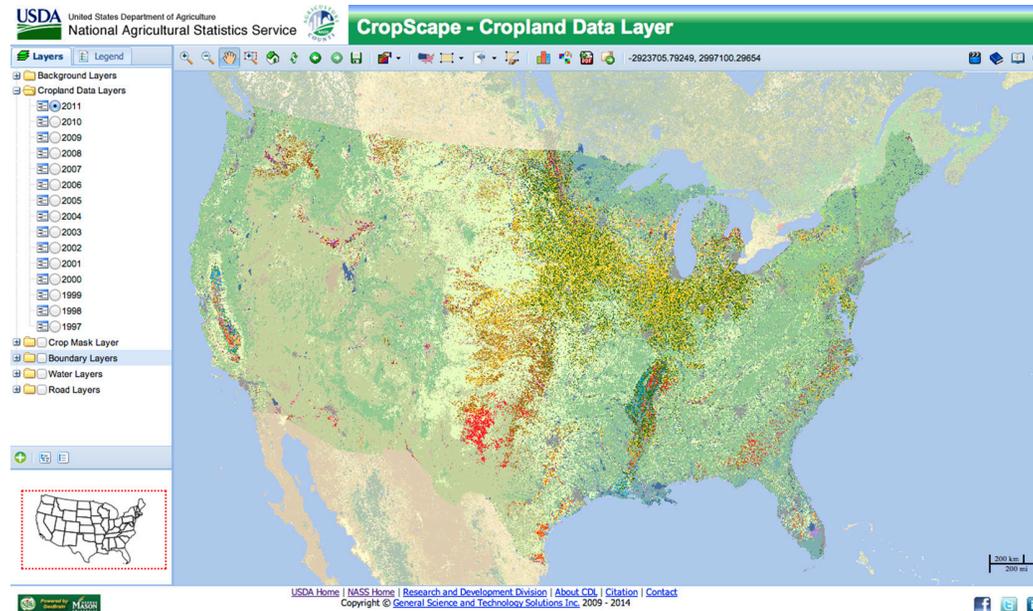
extensive, detailed geospatially based crop map produced by any nation, and it is available three months after harvest.

The Landsat-based crop maps are compared to ground-based observations reported through surveys, providing robust validation, says Mueller. Outside the United States, where little ground data are available, satellite observations become even more critical. The necessity of independent satellite observations became starkly clear in the 1970s.

Foreign Agricultural Service

In the early 1970s, world wheat harvests failed. But in the United States, crops were very productive, leading to a large stockpile. Before the United States realized that there was a global shortage, the Soviet Union bought 15 million tons of wheat at low prices. This left the United States and other countries with a shortage and drove up the cost of wheat 200 to 350 percent.

Determined not to be blindsided again, the USDA established a global crop surveillance and reporting system in the Foreign Agricultural Service. Using satellites allowed them to monitor crops globally, even in Russia and China during the Cold War. The information provides price stability. ▶



CropScope displays crop production data in a map interface.

“Landsat is beneficial to NASS because it provides a mechanism to enhance the statistics. We blend information from the satellite data with survey data.” —Rick Mueller



That price stability matters because agriculture is still the base of world economies. Food prices affect each of us—from the leader of a nation trying to grow a national economy to the small-time family farmer trying to make a living or the parent trying to feed a family.

Learn More:

Landsat - Protecting the Price of Bread
http://landsat.gsfc.nasa.gov/news/news-archive/soc_0010.html

CropScape
<http://nassgeodata.gmu.edu/CropScape/> ■

Meet Rick Mueller, Spatial Analyst with the U.S. Department of Agriculture



Rick Mueller
 Section Head
 Spatial Analysis Research Section
 Research and Development Division
 U.S. Department of Agriculture National
 Agricultural Statistics Service
 Fairfax, Virginia

Rick Mueller sees the world in pictures. As a mapmaker, he joined the National Agricultural Statistics Service just as the group was starting to use satellite images and geospatial data to supplement large data tables of crop statistics. “Seeing the potential of satellite imagery to communicate crop extent was inspiring,” says Mueller.

Mueller graduated from the University of Maryland College Park with a degree in geography. He began his career

at the National Oceanic and Atmospheric Administration as a cartographer working on aeronautical charts. After six and a half years, he returned to school to get a master’s degree in business from Johns Hopkins University.

When Mueller began working for the National Agricultural Statistics Service (NASS) in 1993, it was natural for him to think about transforming the table-based crop statistical reports into graphical mapping products. “I was interested in developing a product that leveraged the power of the GIS (geographic information systems) to the world.”

As Mueller moved from analyst to manager while at NASS, he saw technology develop enough to make his vision possible. Computer processing power advanced, satellite data became more abundant and now freely accessible, and mapping software became more powerful and sophisticated. Working with a team of geographers, statisticians, and information technology experts, Mueller led the development of CropScape, a powerful online mapping tool that allows anyone to explore crop information by location.

“We now have a cool way of disseminating data. No other country is doing this quite like us!” says Mueller.

Satellite Data Requirements:

 8-day revisit (5-7 day preferred)

 30 m resolution

 Vis, NIR, SWIR

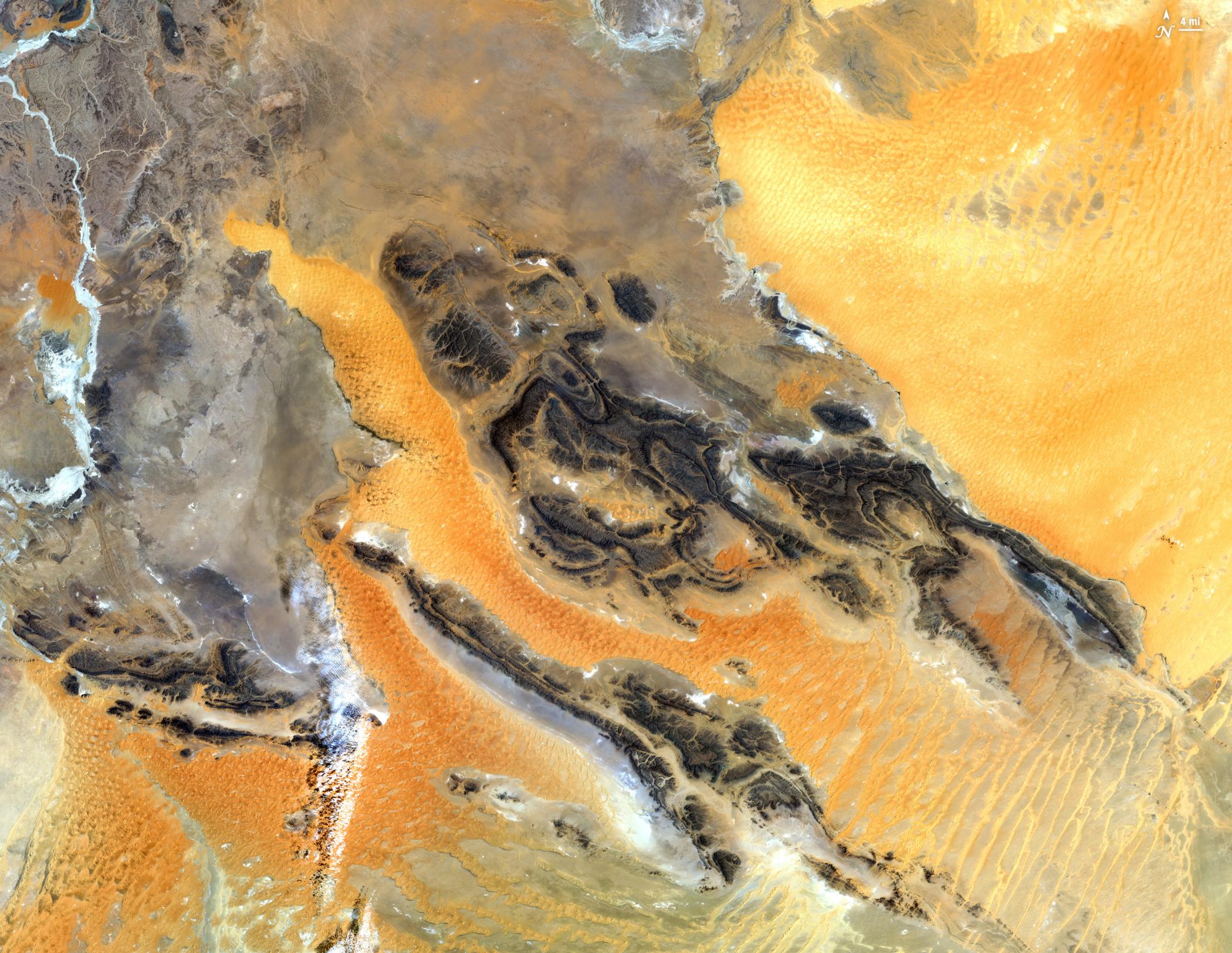
 Global coverage

 Archive continuity & consistency

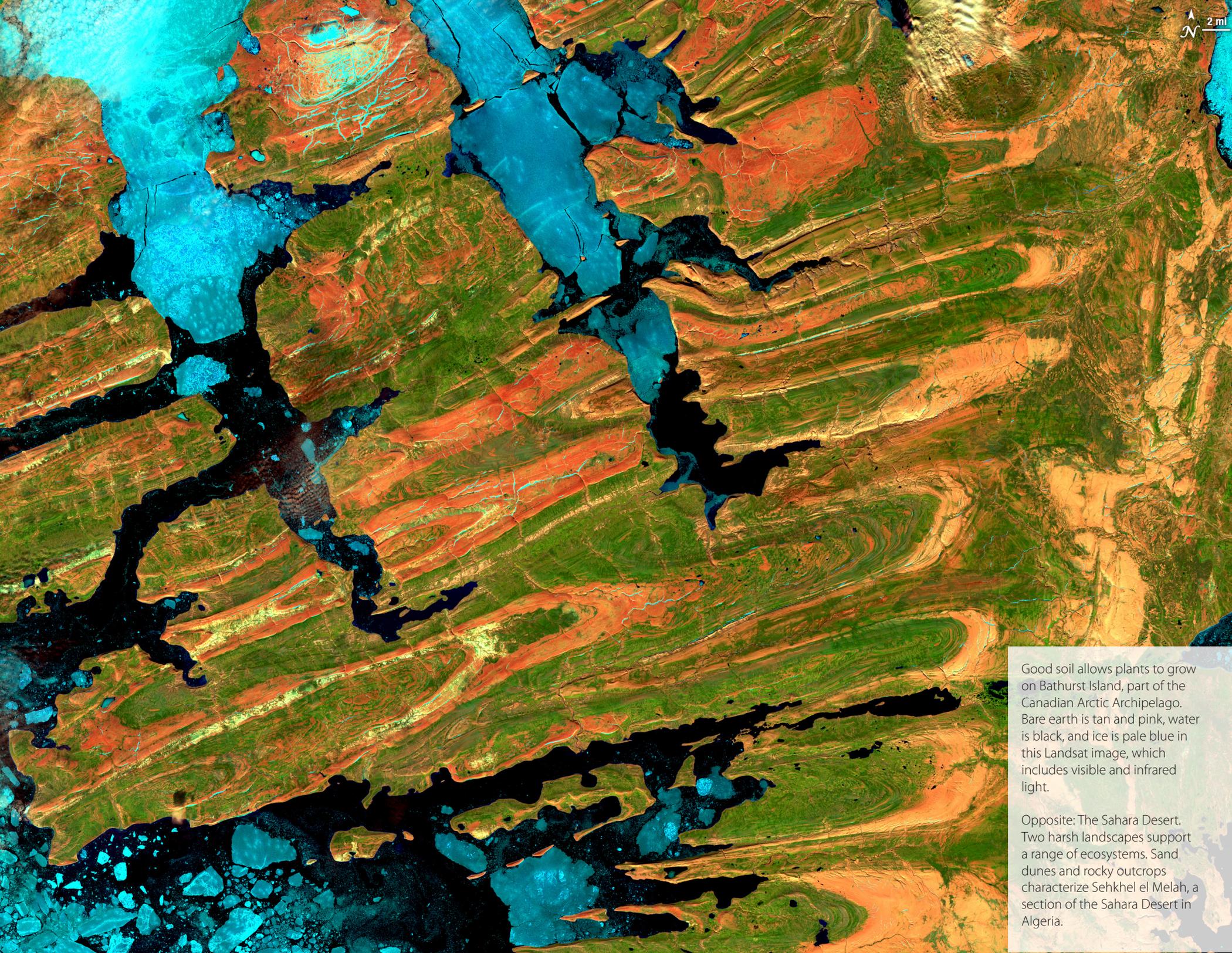
 Rapid delivery of free, unrestricted data

 Coregistered geolocation

See inside back cover for more information



↑
N 4 mi



Good soil allows plants to grow on Bathurst Island, part of the Canadian Arctic Archipelago. Bare earth is tan and pink, water is black, and ice is pale blue in this Landsat image, which includes visible and infrared light.

Opposite: The Sahara Desert. Two harsh landscapes support a range of ecosystems. Sand dunes and rocky outcrops characterize Sehkhel el Melah, a section of the Sahara Desert in Algeria.



Mapping the Western Pine Beetle | Tassia Owen

Standing at the foot of a mountain inside Sheepshead Recreation Area just outside of Butte, Montana, Sue Cummings remembers the day she married her husband 25 years ago. She recalls her casual off-white dress and the deep green of the forest. The smell of pines still brings her back to that day.

In the summer of 2011, Sue almost didn't recognize the place. The population of mountain pine beetles, which had always been present in the forest, had exploded recently due to warmer winters and drier summers. The beetles killed many of the trees that set the scene for her marriage vows. "I was sad to see the devastation of the pine beetle epidemic. Although I had seen it elsewhere, when it is somewhere you have great memories of, it hits you harder," says Cummings.

Cummings is not the only person finding beloved forests transformed of late. Outbreaks of the mountain pine beetle have swept across western forests, impacting more than four million acres. One of the best ways to see the full extent of the infestation is the National Insect Disease Risk Map. Jim Ellenwood, Frank Krist, Frank Sapio and others who developed the map use annual aerial surveys and Landsat data to measure the extent of the damage from the mountain pine beetle and to create models, which ▶



Photo Information
 Opposite: From the sky, areas that are infested by the mountain pine beetle appear red compared to the bright green areas that are healthy forest and not infested.
 Credit: William M. Ciesla, Forest Health Management International. Below: A lodgepole pine tree infested by the mountain pine beetle, with visible "pitch outs."
 Credit: Padraic Ryan. Above: A mountain pine beetle is a very tiny insect, averaging around 5 mm long. Although small, the beetle is the number one insect and disease risk for forests in the United States. Credit: USDA Forest Service.



[Image information](#)
Landsat 5 acquired this image of a beetle-damaged forest in Rocky Mountain National Park on September 28, 2011. Healthy forest is dark green, while infested forest is brown. Exposed rock or bare earth is pink. Credit: NASA/USGS

are used to predict the outcome of disease and insect infestations across the United States.

Understanding the extent of a pine beetle outbreak is important because weakened and dead trees can fall in campgrounds, roads, or trails, posing a hazard to people. Fallen, dry trees are also a significant fire hazard. Land managers mitigate the hazard by removing infected trees near populated areas.

Landsat Maps Pine Beetle

Recently, the map has improved thanks to 30-meter observations from Landsat satellites. Incorporated into the map for the first time in 2012, Landsat measurements help scientists identify forests that are at risk of infection. A number of factors make forests particularly vulnerable to pine beetle infestations, including forest density, tree age, and tree type—all things that Landsat can help assess.

Landsat measures both visible and infrared light reflected from forests. Healthy trees absorb blue and red visible light and reflect infrared light. A densely forested area will reflect infrared light and absorb more visible light than a sparsely forested area. By measuring the amount of reflected light across the electromagnetic spectrum and combining that informa-

tion with other significant data such as soil type, Ellenwood and his colleagues are able to determine the density of the forest. Dense forests are vulnerable because the mountain pine beetle can move more rapidly during an outbreak.

Tree type matters because, while mountain pine beetles make their home in many different species of pine trees, they prefer aging Lodgepole, ponderosa, sugar, and western white pines. The beetle spends most of its life as larvae living under the bark of trees and feeding on the inner bark and the phloem, the first layer of living tissue under the bark that carries nutrients to the different parts of the tree. The mountain pine beetle cuts off the supply of nutrients to the tree, preventing the tree from getting all of the things it needs to live. “It’s kind of like it destroys the cardiovascular system of the tree,” says Hecker. “Without our arteries and veins we wouldn’t survive. It’s the same for trees. Without the pathways for nutrients to move around the tree, it can’t survive.”

Landsat can help scientists determine which trees dominate in a forest because large tree stands of the same tree type look similar in Landsat images. By combining tree type and forest density, Ellenwood and his colleagues build models that

predict the risk of of disease and insect infestations across the United States.

“We know there are forest health issues out there, we want to be proactive. The National Insect and Disease Risk Map gives us the ability to be proactive at a strategic level,” says Ellenwood.

Responding to Pine Beetle Infestations

Managing bark beetle infestations is becoming more important. According to the 2006 National Insect Disease Risk Map, the mountain pine beetle is projected to destroy 750.5 million square feet basal area of pine forests by 2020. Basal area is a measure of the density and size of trees. The insect has caused similar devastation in Canada, particularly British Columbia.

The current outbreak is epidemic due to what researchers have called the perfect storm: above normal temperatures in winter and abundant food supply. Without a cold winter there was no “hard prolonged freezing temperatures to kill the larva,” according to Hecker. Also, most of the forests in the West are the same age, about 150 years old—near the maximum age for these types of forests. Since older trees are more susceptible to the mountain pine beetle, outbreaks have been extensive. ▶

ECOSYSTEMS

The mountain pine beetle can rapidly kill millions of trees during an outbreak, leading to large changes in ecosystems west of the Mississippi River. In fact, of all insects and diseases that impact forest health, the mountain pine beetle is the largest threat to healthy western forests. “It’s like a wildfire moving in slow motion,” says Hecker.

This “slow moving fire” can give rise to actual fire. Acres of dead, dry trees can be fuel for wildfire. To minimize both fire risk and the potential for damage or injury from falling trees, land managers remove downed trees from recreation and camping areas. Since fires can affect water quality, land managers also take action if a beetle-affected area is in a community’s watershed. Fire destroys forests and causes the soil to repel water. Both effects allow topsoil to erode down watersheds, clogging waterways with sediment and debris and affecting water quality.

Insects and diseases impact both the forest and the animals that live there, and Landsat data are helping scientists assess how much ecosystems are changing as pine beetle outbreaks spread. When trees that are brown, red, and dead replace lush green trees, birds, squirrels, nuthatches, grouse and porcupines disappear. Voles, ▶



Before and after images from the Landsat 5 satellite reveal beetle damage in Rocky Mountain National Park in Colorado. In 2005 (image on top) the healthy forest appears bright green, but in 2011, (image on bottom) many of the bright green areas were replaced by a drab brown, indicating portions of the forest that have been attacked by the mountain pine beetle. Image comparisons allow land managers to identify areas that may be impacted by infestations. Credit: USGS/ NASA’s Earth Observatory



Photo Information
Above: The mountain pine beetle lives under the bark of trees, feeding on the inner bark and the phloem. This cuts off the supply of nutrients to the tree, eventually killing it. Credit: USDA Forest Service



[Photo Information](#)

Above: Land managers remove trees killed by pine beetles to minimize the hazard of a tree causing damage as it falls. Removing infected trees near roads, campground, or other populated areas is the normal response to an outbreak. Credit: USDA Forest Service

Opposite corner: Chipmunks are among the animals that move in to areas infested by mountain pine beetle. Credit: Acrylic Artist
Following full-page image: One ecosystem gives way to another as altitude changes at Maroon Lake in the White River National Forest, Colorado. Credit: USDA Forest Service.

salamanders, mice and chipmunks move into the coarse woody debris left by the mountain pine beetle. These animals churn the debris like a farmer churns compost helping air, water and nutrients to infuse the soil, while these animals assist in replanting by inadvertently moving seeds through the soil.

Terrestrial Ecological Unit Inventory

To understand the extent of changing ecosystems, scientists at the US Forest Service Terrestrial Ecological Unit Inventory program use Landsat data to merge soils and vegetation information, which can then be

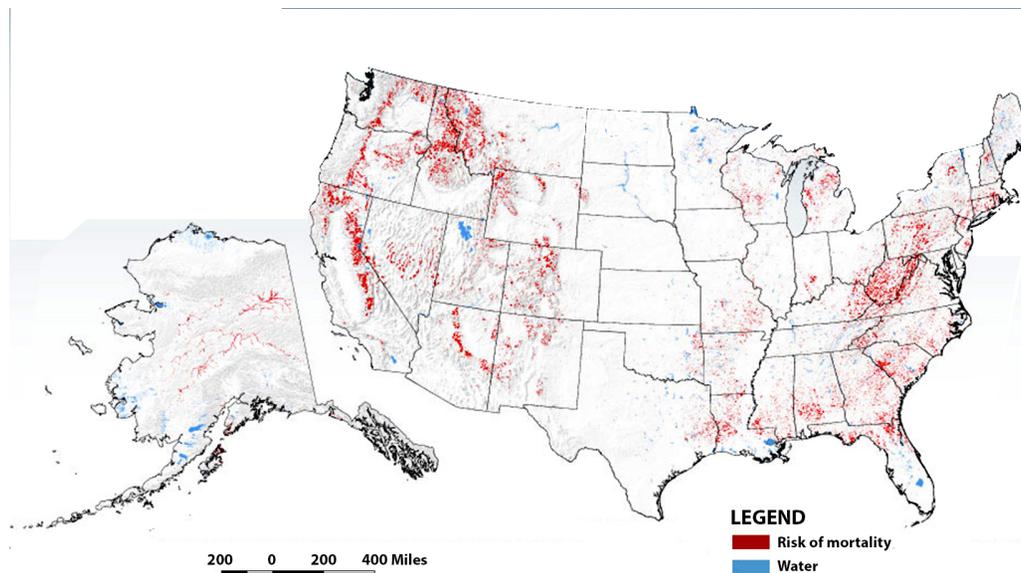
used as indicators of animal populations. Using Landsat measurements of both infrared and visible light, scientists are able to identify the different soil and vegetation types that mark unique ecosystems.

The Terrestrial Ecological Unit Inventory was developed in the 1990s in an effort to coordinate the efforts of a number of scientists who study different parts of an ecosystem. Traditionally soil scientists study soil, botanists study plants, and biologists study animals, but in fact “the flora and fauna meld all of the pieces together to make a habitat or ecosystem,” says Bob Benton of the US Forest Service’s Remote Sensing Application Center in Salt Lake City, Utah.

Once Benton and others classify ecosystems using Landsat and other remote sensing data, scientists from the regional offices go into the field to verify that the landscape patterns are indicative of the type of ecosystems thought to be present.

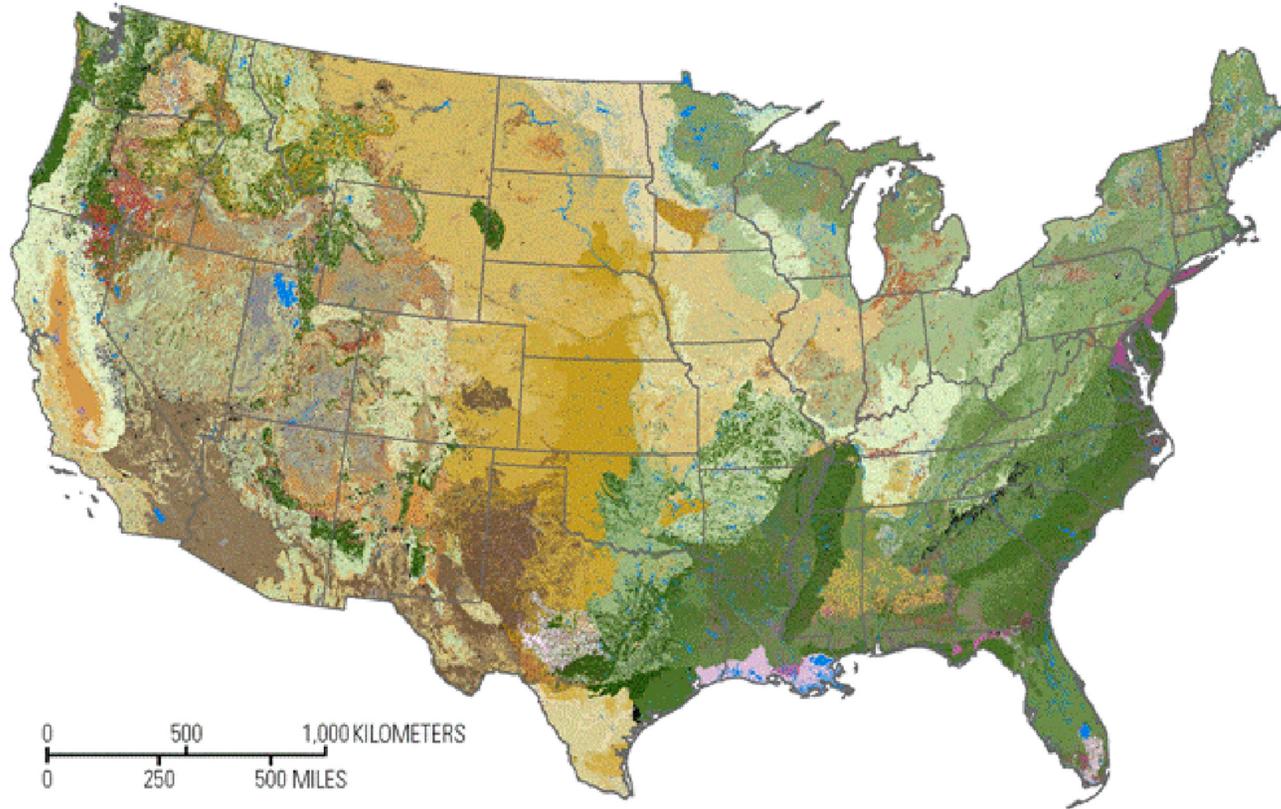
As one may expect, it is difficult to tell exactly what types of flora and fauna are in an area from the satellite image. “Nature seems to abhor sameness,” says Bob Benton. Scientists are able to make educated guesses, but the ground verification process brings more certainty to their mapping, leading to a better catalog of the existing ▶

Mapping Insect and Disease Risks with Landsat



The National Insect and Disease Risk Map (NIDRM) is generated from many data sources, including Landsat, 2006. Credit: USDA Forest Service

ECOSYSTEMS

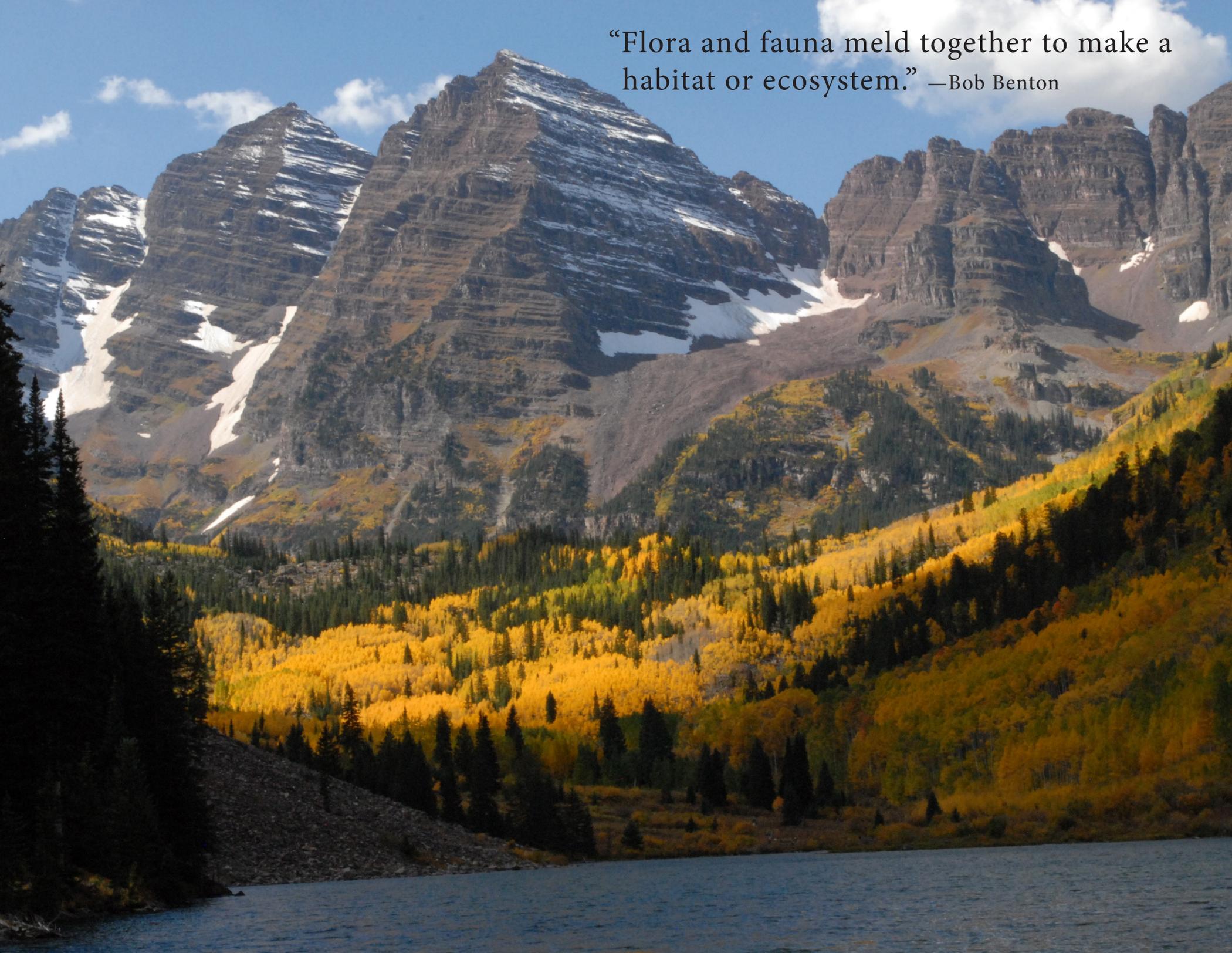


Terrestrial Ecosystems

- | | |
|--|---|
|  Forest and Woodland Ecosystems |  Woody Wetland Ecosystems |
|  Herbaceous Ecosystems |  Herbaceous Wetland Ecosystems |
|  Shrubland Ecosystems |  Sparsely Vegetated Ecosystems |
|  Steppe/Savanna Ecosystems | |
|  Water | |

Landsat data helps scientists define the extent of seven different ecosystems in the United States. Maps are available at <http://rmgsc.cr.usgs.gov/ecosystems/usa.shtml> Credit: USGS

“Flora and fauna meld together to make a habitat or ecosystem.” —Bob Benton



ECOSYSTEMS

ecosystems in the inventory. The Terrestrial Ecological Unit Inventory's "purpose is to give Forest Managers and people who make decisions, a scientific basis to anchor their decisions," says Benton.

When faced with tough choices land managers are able to use inventories like the Terrestrial Ecological Unit Inventory to say, as Benton stated, "This is how I made my decision, it's consistent and this is how it is adapted to the land."

As people like Sue Cummings continue to spend time at recreation areas and hiking through forests, they will continue to see the land change. Through improved monitoring and better models more proactive measures can be taken to mitigate the effects of insects and disease and to gain a better understanding of the ecosystems that they affect. ■

Meet Bob Benton, Inventory Coordinator for the Terrestrial Ecology Unit



Salt Lake City, Utah

Bob Benton

Inventory Coordinator
Terrestrial Ecology Unit
U.S. Department of Agriculture Forest Service

"Expect that 10 years from now, you won't be doing what you think you'll be doing," says Bob Benton, Terrestrial Ecology Unit Inventory Coordinator at the Remote Sensing Applications Center of the United States Forest Service, when asked if he has any advice for people just starting their careers. "Whatever you're doing now won't be there 10 years from now and you'll have to be relevant in some other way."

Benton is no stranger to changing careers. After spending most of his life working in the banking industry as the Chief Information Officer with Associates First Capi-

tal Bank, he hit a crossroads. Citigroup bought the bank and he could choose to relocate to Baltimore, Maryland or to stay and try to find work in Salt Lake City, Utah. He chose the latter, going back to get his master's degree at 58 years old.

Attending classes, surrounded by students that were the same age as his children, wasn't something that he or most people think they'll be doing at a time when many are preparing for retirement. "I was the oldest intern," says Benton about his time interning at the Remote Sensing Applications Center. After completing his master's degree with a focus on remote sensing, Benton reentered the workforce, working his way up from intern to management.

Benton works with a number of researchers, but his background in business gives him a fresh perspective. "They [researchers] break down the pieces." Benton on the other hand, "looks at how things work in aggregate, not how things work in particular." Working with a great group of researchers, Benton is "working towards a common outcome." After a very circuitous route, Benton enjoys what he does and is able to spend time playing in the outdoor playground of ski areas and mountain hikes nearby Salt Lake.

Satellite Data Requirements:



8-day revisit (4-day preferred)



5-30 m resolution



Vis, NIR, SWIR



Global coverage



Archive continuity & consistency



Free, unrestricted data



≤ 5% radiance calibration



12-bit bit data digitization

See inside back cover for more information





The herringbone pattern occurs because people cut trees along roads.

Opposite: Landsat's 40-year record helps countries track deforestation over time. This image pair shows the Amazon rainforest Brazil's Rondonia state in 1989 (left) and 2008 (right).



FORESTS

Counting the World's Trees | Holli Riebeck

How many trees are there in the world? It's more than a trivia question, and one that the United Nations Food and Agriculture Organization (FAO) has been striving to answer every 5 to 10 years since 1946.

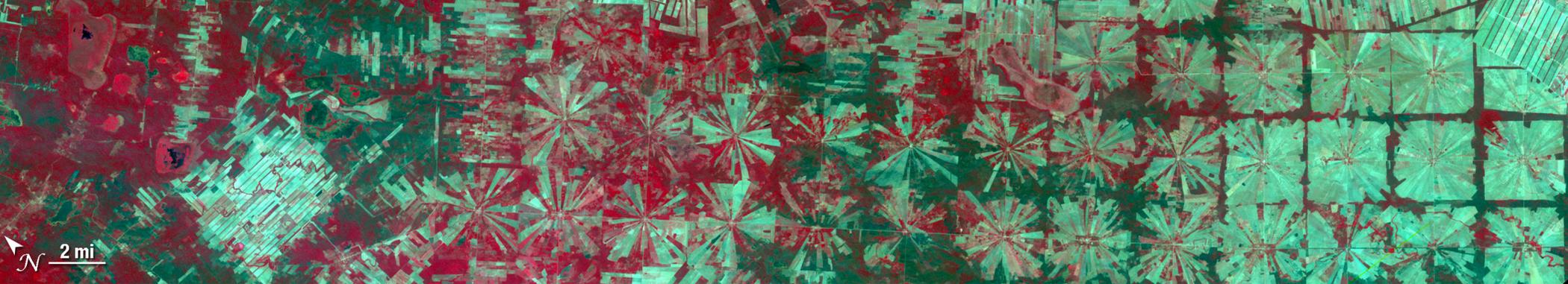
When the United Nations first began its global surveys of the world's forests, it wanted to know how much timber remained. Decades later, the surveys—called the Global Forest Resources Assessments (FRA)—serve a far wider purpose.

“The basic fact is that natural resources, like forests and land to grow crops, are getting more and more scarce,” says Alan Belward in an interview with EarthSky. Belward heads the Land Resource Management Unit of the European Commission's Joint Research Center (JRC) in Ispra, Italy, where he worked on the latest UN global forest remote sensing survey in 2010—the most comprehensive survey to date.

“There are all sorts of competing demands on our resources,” continues Belward. “Do you use a forest as a carbon sink? Do you use it as a protected area for biodiversity? Or do you use it for fuel wood? To make sensible decisions on trade-offs between different uses, you need evidence on where these resources are, what sort of condition they're in, and how they're changing.” ▶



[Photo Information](#)
Opposite: Oregon's old growth coastal forest is an important wildlife habitat. Credit: David Patte/U.S. Fish and Wildlife Service. Below: Forests are a source of clean water. Credit: David Patte/U.S. Fish and Wildlife Service. Above: Recreation is one of many uses for forest landscapes.



[Image information](#)

Landsat satellites have been in orbit since 1972, providing a long record of deforestation patterns. This image shows an unusual star-shaped pattern in Bolivia. The image was made from near infrared, red, and green light. Forest is dark red, while bare to lightly vegetated ground ranges from tan to green.

Landsat, a Consistent Ruler

The global surveys provide decision makers with a regular, consistent assessment of the extent of the world's forests and how they are changing. The surveys have traditionally been a compilation of reports from individual countries. Norway and Nigeria each survey their forests, for example, and report forested area to the UN Food and Agriculture Organization. However, the two countries may use different survey methods, and so the measurements between countries aren't necessarily comparable.

More recently, thanks to Belward and his colleagues, the surveys have incorporated Landsat satellite measurements of forest extent as a consistent "ruler" for all countries. "We've taken about 13,000 plots around the world which are distributed uniformly, every 60 miles or so, north, south, east, and west. We take a sample plot and we map the change in an area of about 25 acres. That is done 13,000 times in 1990, in 2000, and in 2005," says Belward. This global remote sensing survey is a complement to the compilation of national reports carried out under the Forest Resource Assessment of 2010.

Previous efforts carried out in 1990s used between 100 (TREES-II survey) and 120 (FAO FRA-2000) Landsat images,

says Frédéric Achard also of the European Commission's Joint Research Center. The Food and Agriculture Organization and the Joint Research Center were able to use 13,000 images at three dates over 190 countries in the most recent survey because Landsat data are now available from the United States Geological Survey free of charge. "In the 1990s the cost of one Landsat TM image was about \$2,500. The cost went down to about \$600 in the mid 2000s before being released free of charge starting in December 2008. The cost of the imagery was prohibitive to cover extensive areas" says Achard.

The change from 100 images to 13,000 is significant because the view from Landsat is ideal for forest monitoring. Each pixel in a Landsat image measures 30 meters by 30 meters—about the size of a baseball diamond. "To see fine-scale deforestation, we need Landsat," says Achard. "A coarser resolution satellite doesn't allow providing accurate estimates of deforestation on its own."

Seeing Forest Health

The images are far more than photos, says Belward. Landsat records reflected light in both visible wavelengths and infrared wavelengths invisible to the human eye. By measuring the strength of reflect light in multiple wavelengths, research-

ers can get a sense of not just where the forests are, but how healthy they are.

"We're able to pick up subtle changes in the forest canopy. You can see where you've got largely undisturbed forests or where a logging road has gone in or where it's been clear felled to convert it to other lands," says Belward.

Computer algorithms help researchers sort through hundreds of thousands of scenes and classify forested versus non-forested ground. "The computers work well where the Landsat images have a high spectral contrast between forested and non-forested land like in the Amazon basin during short dry season," says Achard. Low contrast areas like the dry forests and shrublands of Africa pose a challenge. In these cases, regional experts also examine the images and provide visual corroboration to correct the computer outputs.

Global Deforestation

Achard, Belward and others also use Landsat data to determine how forests are changing. Landsat satellites provide a 40-year record, which means that measurements taken in 1985 can be compared to measurements taken in 2012. This allows researchers to map change over time, offering a startling picture of how quickly the world's forests are disappearing. ▶

FORESTS



[Photo Information](#)
Above: The need for wood products helps drive deforestation.

Listen to Alan Belward talk about the pressures on the world's forest at http://landsat.gsfc.nasa.gov/news/news-archive/soc_0033.html



Protecting the biodiversity of forests sometimes conflicts with other demands on forest resources such as timber. Making national and international decisions on forest management requires knowing where forests are, what conditions they're in, and how they're changing. Researchers are conducting large-scale surveys of forests of around the globe with the help of Landsat. Credit: terex (left) and Taina Sohlman (right), both Fotolia.com.

“About 30 percent of the whole planet's land area, starting in 2005, was covered in forest. And rather worryingly between 1990 and 2005, we've lost about 180 million acres of forest,” says Belward. “We're losing about a football field worth of forest every four seconds of every minute of every day. That's net loss. That's including all the new trees that have been planted around the world.”

Reducing Deforestation

The ability to see deforestation over the past forty years is increasingly important.

Not only does the historical view provide context for future decisions, it may become the basis for international policy. Under an emerging mechanism of the United Nations Framework Convention on Climate Change (UNFCCC) called Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+), donor countries agree to provide incentives to developing countries to reduce their deforestation and degradation rates and to leave their forest intact in order to reduce global carbon emissions and mitigate future climate change.

The 2010 Global Forest Resources Assessment revealed that deforestation was releasing nearly a billion tons of carbon into the atmosphere per year (0.9 +/- 0.7 Pg C), a decrease from the previous decade. The UNFCCC REDD item aims to continue the downward trend. Developing countries will voluntarily set carbon emission reference levels based on past rates of deforestation.

To set accurate reference levels which will be used to account for emissions reduction rates, countries need to figure ▶



Photo Information

Above: Forests such as this at Victoria Falls serve as storage areas for carbon. A program called, "Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+)" provides incentives to countries to leave their forests intact and thus to reduce global carbon emissions. Landsat provides an objective, reliable source of landscape scale data on how forests are changing over time, and so serves as an important foundation for REDD.

out historical deforestation and emissions. The base year 1990 is used for the Kyoto Protocol, but the base period for REDD+ is not fixed and will depend on individual country capacities and conditions, says Achard. "Wall to wall coverage of the Tropics with Landsat has existed since the 1990s, so we can get historical deforestation estimates for the last 20 years to feed negotiations and allow producing reference levels." These historical estimates must be as accurate as possible if

Papua New Guinea

1990



2001



Landsat images show change from 1990 to 2001 in a once-forested area near the southeastern tip of mainland Papua New Guinea. Researchers using Landsat and other data sources found evidence of rapid deforestation and degradation, driven primarily by logging, subsistence agriculture, fires, and the development of mines and plantations. "To see fine-scale deforestation, we need Landsat," says Achard. "A coarser resolution satellite doesn't provide accurate estimates of deforestation on its own." Credit: NASA's Earth Observatory

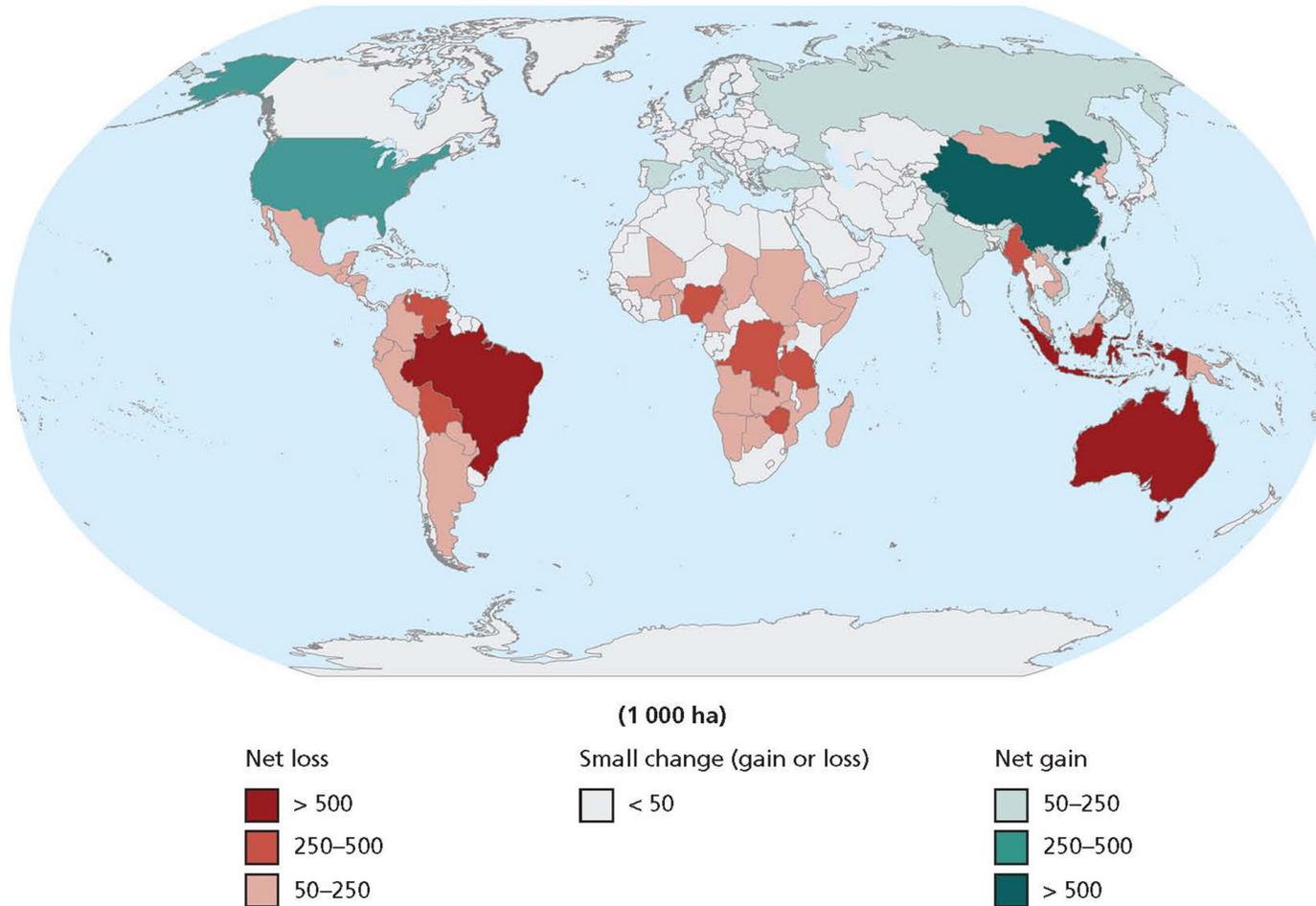
the program is to work as a market force.

"Countries that have high historical deforestation rates like Brazil and Indonesia have the potential for large payoff by reducing these rates" says Achard. But countries with smaller emissions can also expect incentives through conservation and enhancement of forest carbon stocks. All countries will be rewarded in providing accurate estimates of both historical and current emissions by getting larger pay-

ments. Landsat provides consistent, unbiased estimates of forest cover and deforestation for all countries. The Landsat Data Continuity Mission, to be called Landsat 8 after launch, ensures that observations will be available into the future (from 2013).

Ongoing observations are necessary because the UNFCCC REDD+ mechanism requires annual reports that include the number of hectares of forest lost and the amount of carbon emitted as a result. ▶

FIGURE 5
Annual change in forest area by country, 2005–2010

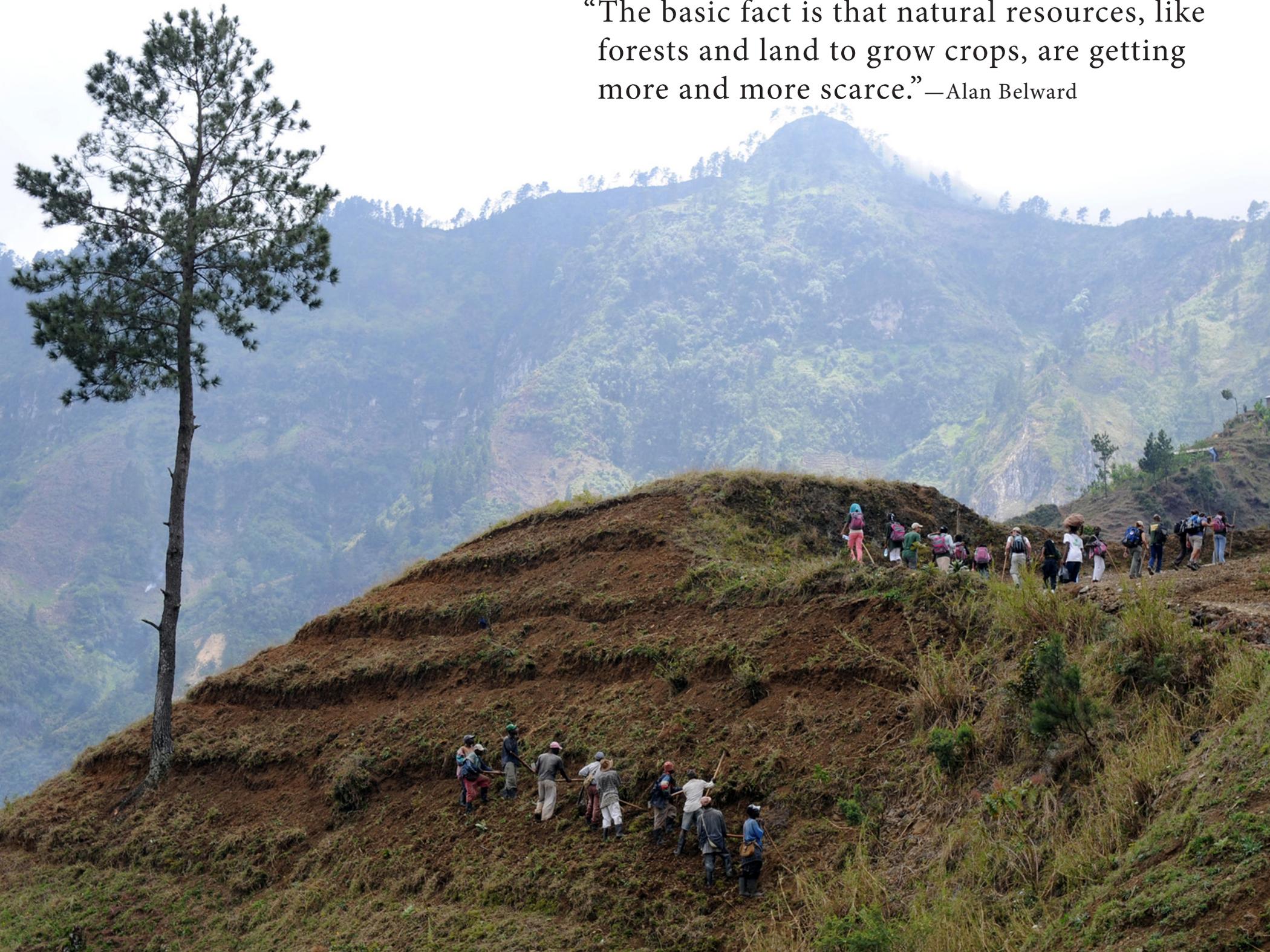


Landsat data helped analysts determine how much forest was lost throughout the world between 2005 and 2010. Map courtesy United Nation's Food and Agriculture Organization's 2010 Global Forest Resource Assessment.



Photo Information:
 Not all forest clearing occurs in tropical regions. Landsat 5 acquired this image showing harvest around Mt St Helens in 2011. Tan squares are clear-cut areas. Young forest planted after a clear cut is pale green, while mature forest is dark green. Following full-page photo: Finding land to raise food for the world's growing population places pressure on forests. Decades of deforestation and overfarming have stripped the hillsides of Haiti, leaving less than two percent of the country forested. Credit Kendra Helmer, USAID/Haiti.

“The basic fact is that natural resources, like forests and land to grow crops, are getting more and more scarce.” —Alan Belward



FORESTS

“Estimates have to be as accurate as possible,” says Achard. “Donors will probably pay only for real reductions in emissions.”

REDD+ is still in an early pilot phase with a handful of countries. It is uncertain how REDD+ will be implemented on a larger scale in an operational phase. The challenge is that many developing countries lack resources to produce regular accurate annual reporting. Landsat-based estimates of deforestation such as those used in the UN FAO Global Forest Resources Assessments are less expensive than an extensive ground-based survey and may turn out to be essential for the success of any deforestation reduction program.

Defining Forest Policy

Regardless of how programs like REDD+ develop, Landsat will continue inform policy through the UN Global Forest Resources Assessment. During Landsat 8's lifetime in orbit, the world's population will likely grow, increasing conflicting demands for food and forest products.

“Our policy makers have an increasing demand for science-based evidence to support their work,” says Belward. “One of our jobs is to provide that evidence.” ■

Meet Frédéric Achard, Scientific Project Leader for the Joint Research Center



Frédéric Achard
Scientific project leader
Joint Research Center
European Commission
Ispra, Italy

“I like to be in the mountains hiking, alpine skiing, or rock climbing,” says Frédéric Achard of Nice, France. When it came time to choose a career field for his university education, Achard wanted to do something to preserve the resources that propelled him to spend his time outdoors. “I knew I wanted to work in the forestry

field, managing public forests for the National Forest Office in France.”

After two years of studying math and science, he entered the Ecole Polytechnique in Palaiseau (20 km south of Paris) followed by National School for Rural Engineering, Water and Forests in Paris, where he obtained the equivalent of a master's degree in forestry. Opportunity led him a different direction than he planned. The school offered a PhD program in remote sensing, for which he was hosted by an Institute specialized in tropical vegetation mapping at University of Toulouse. “There were good opportunities for research in remote sensing applied to tropical forest assessment,” says Achard.

Rather than manage France's forests, Achard decided to apply his expertise to monitoring the world's forests. He is now a scientific project leader with the European Commission's Joint Research Center where he works on TREES-3, a project that uses Landsat data to map forest cover changes throughout the Tropics and Eurasia. “The research is challenging. It's not routine. I have a lot of freedom to explore innovative new ideas.”

Satellite Data Requirements:



16-day revisit



5-30 m resolution



Vis, NIR, SWIR



Global coverage



Archive continuity & consistency



Free, unrestricted data



geolocation \geq 15 m



\leq 5% radiance calibration

See inside back cover for more information

Built to Serve Society

Images from the Landsat program have become essential for many organizations and applications. Each user community has specific requirements for the quality and content of the data that comprise those images. Many applications require comparisons between current imagery and past imagery, thus placing a priority on acquiring comparable, well-calibrated data mapped consistently to the Earth's surface. All users need free access to both current and past imagery. In some cases, such as fire and crop monitoring, user communities need data soon after acquisition.

Glossary of Requirements

Revisit Time

The time that elapses between two consecutive overpasses of a location. Because of cloud cover, the period between clear observations for an application may be longer than the revisit time. To get seasonal observations, the satellite must acquire several images during the season to increase the likelihood that the area will be cloud free during at least one overpass per season.

Spatial Resolution

Spatial resolution refers to the amount of detail shown in the image or the size of

a pixel on the ground. For most LDCM observations, each pixel on the ground is 30 meters by 30 meters, about the size of a baseball diamond.

Spectral Coverage

Most applications require observations in specific wavelength regions of light. Spectral coverage refers to the range of wavelengths observed by a sensor. In the table, Vis refers to visible light, NIR refers to near infrared, SWIR refers to short wave infrared, and TIR is thermal infrared. LDCM collects data for multiple spectral bands within each region.

Geolocation

Geolocation is the accuracy with which each pixel in a satellite image is mapped to the Earth's surface. Pixels within LDCM images are referenced to within 12 meters of their actual location. Coregistration from scene to scene acquired on different dates is important so that users can compare scenes and know that they show the same location on the ground.

Radiance calibration

Landsat pixel values record the absolute intensity of light received by the sensor. Radiance calibration refers to the accu-

racy with which the sensor records that intensity. Five percent radiance calibration required by most applications is the uncertainty relative to the actual intensity.

Data Digitization

The number of bits used to represent each pixel value in an image. The number of bits reflects the sensitivity of the data to the intensity of light received by a sensor. As an analogy, six-bit data, providing integer values between zero and 63, are required to record the range of measurements available from a foot-long ruler marked every quarter inch (48 gradations). Eight-bit data, zero to 255, are necessary to record the range of measurements available from a one-foot ruler marked every sixteenth inch (192 gradations).

LDCM Characteristics vs. Application Requirements

		Spectral Coverage				Spatial Resolution				Revisit Time				Geolocation	Radiance Calibration	Data Digitization		
		Vis	NIR	SWIR	TIR	<10m	<20m	<30m	<60m	<100m	<4 Days	<8 Days	<16 Days	<30 Days	≤15 m	≤5%	≥8 bit	≥12 bit
	LDCM						15 m pan band	30m Vis, NIR & SWIR Bands		100m TIR bands		with Landsat 7	LDCM alone		12 meters	≤5%	≥8 bit	12 bit
Application Area	Fire									X								
	Land Use									X		X						
	Water Use									X	X	X						
	Food									X	X							
	Ecosystems									X	X							
	Forests																	

Solid Gray = requirements

X = desired characteristics

The Landsat Data Continuity Mission meets many, but not all, of users' growing requirements. This table compares the satellite's capabilities with data requirements from select user communities. Data in the table come from an informal survey of users within national land management agencies. Requirements are not discussed in detail.

Landsat represents the world's longest continuously acquired collection of space-based moderate-resolution land remote sensing data. More than four decades of imagery provides a unique resource for those who work in agriculture, geology, forestry, regional planning, education, mapping, and global change research. Landsat images are also invaluable for emergency response and disaster relief.

As a joint initiative between the U.S. Geological Survey (USGS) and NASA, the Landsat Project and the data it collects support government, commercial, industrial, civilian, military, and educational communities throughout the United States and worldwide.

Plans for the Landsat Data Continuity Mission (LDCM) are currently underway, with launch scheduled no earlier than February 11, 2013. As with previous partnerships, this mission will continue to acquire Landsat-quality data that meet both NASA and USGS scientific and operational requirements for observing land use and land change.

