



About this issue

This issue of Climate Matters highlights USGS research on patterns and impacts of drought on ecosystems of the western United States, the effects oil and gas development on landscapes, and the processes that influence coastal wetlands.

Science Feature



[Leaf to Landscape: Understanding and Mapping Forest Vulnerability to Hotter Droughts](#)

Science Highlights



[Plant responses to drought on the Colorado Plateau](#)



[Effects of land use on wetland greenhouse gas fluxes and soil properties](#)



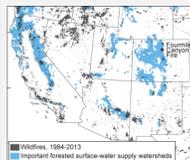
[Hydrologic response to climate change in the Las Vegas Valley](#)



[Climate change and coastal wetlands: the importance of temperature and rainfall regimes](#)



[Landscape Effects of Oil and Gas Development](#)



[Fires, floods, and the future of water supplies in the southwestern U.S.](#)

New and Noteworthy

[Biodiversity Critical to Maintaining Healthy Ecosystems](#)

By James B. Grace, T. Michael Anderson, Eric W. Seabloom, et al.

Science Partnerships

[Managing marsh loss using sediment enhancement to preserve habitat for waterfowl](#)



Brackish tidal marsh at Blackwater National Wildlife Refuge, MD. Photo credit: James Lynch (USGS)

Upcoming Meetings

The [2016 American Association of Geographers \(AAG\) Annual Meeting](#) will be held in San Francisco, California from March 29 – April 2. The AAG Annual Meeting is an interdisciplinary forum where leaders and experts from geography and its allied disciplines intersect to build new partnerships and collaborations.

The American Quaternary Association ([AMQUA](#)) Meeting will be held from June 28–July 2 in Santa Fe, New Mexico. The theme of this year's meeting is "Retooling the Quaternary to Manage the Anthropocene".

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



About this issue

Recently released [climate data](#) indicates that globally averaged temperatures in 2015 were the highest in recorded history. In the conterminous U.S., temperatures were the [2nd warmest on record, and 2015 was the third wettest year on record](#). In spite of high precipitation levels nationally, much of the western U.S. suffered severe drought after very low winter precipitation, and the combined effects of warmer temperatures and low water levels contributed to greater wildfire frequency and intensity, forest die-off, and low reservoir levels throughout the region. Included in this newsletter are summaries of studies sponsored by the [USGS Climate Research & Development Program](#) that examine how these droughts affect forests and dryland ecosystems, how forest fires affect water quality in downstream watersheds, and long-term patterns of hydrologic variability in the western U.S.

Climate Matters includes a sampling of the multidisciplinary research conducted by the Climate Research & Development Program to provide data and improve understanding on the rates, patterns, and consequences of climate and land use change. It also highlights science partnerships with other Federal agencies. We welcome comments and feedback to shape future issues. If you would like to subscribe to future issues, please click the "Subscribe" button on the [Program Newsletter](#) page.

Debra Willard

Coordinator, Climate Research & Development Program

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor

[Jack McGeehin](#), Editor



Managing marsh loss using sediment enhancement to preserve habitat for waterfowl

Tidal marshes are highly productive wetlands characterized by fine-grained sediments, low or no wave action, and frequent tidal flooding. They are found predominantly in sheltered intertidal areas of the mid- and high-latitudes of the world. Tidal marshes are increasingly vulnerable to wetland loss attributable to rising sea level due to global temperature increases. The Blackwater River, a large brackish estuary on the Eastern Shore of the Chesapeake Bay, is an example of a wetland that has seen drastic rates of marsh loss in the last century (Figure 1).



Figure 1. Brackish tidal marsh at Blackwater National Wildlife Refuge, MD. Photo credit: James Lynch (USGS).

Blackwater National Wildlife Refuge (Blackwater NWR) was originally established in 1933 on the Blackwater River near Cambridge, MD as a sanctuary for migratory birds traveling along the Atlantic Flyway (Figure 2). Blackwater NWR contains over 11,700 hectares (ha) of diverse habitat suitable for wildlife, a large portion of which is brackish tidal marsh dominated by saltmeadow cordgrass (*Spartina patens*) and Olney's three-square (*Schoenoplectus americanus*). These Refuge lands provide critical food resources and shelter for migrating waterfowl including Canada geese, snow geese, tundra swan, and more than 20 species of duck. Since Blackwater NWR was established, more than 2,000 ha of marsh have been lost due to sea-level rise and subsidence (the gradual sinking of land). Maximizing suitable marsh habitat is crucial to the waterfowl management strategies for the Refuge; a loss of this habitat means a loss of the goods and services available for migratory and resident wildlife species.

For nearly 20 years, researchers from the U. S. Geological Survey Climate Research & Development Program (USGS) have partnered with the U. S. Fish & Wildlife Service (USFWS) Blackwater NWR to study the biological and physical processes driving the loss of their marsh. USGS researchers first developed an ecological model that predicted conversion and loss of refuge habitat with varying rates of sea-level rise. The model allowed Blackwater NWR natural resource managers to identify areas of the refuge most vulnerable to rising sea levels and forecast degradation of marsh habitat and eventual loss to open water.

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



USGS researchers then conducted a series of experiments on above- and below-ground plant growth, decomposition, and sedimentation to better understand the processes influencing the observed changes on the refuge. They employed surface elevation tables which make precise measurements of the soil surface to study small scale changes in the elevation of the marsh (Figure 3). The USGS also conducted experiments using “marsh organs” to determine the flood tolerance of *S. patens* and *S. americanus* (Figure 4). Marsh organs are PVC planters constructed at varying heights within the tidal cycle. They are designed to measure the impact of rising water levels and determine the optimum soil surface elevation and flooding height for maximum growth and development of target plant species. These studies suggested that most of the areas in the Blackwater NWR covered by marsh vegetation were below the optimum elevation necessary to maintain plant health and persistence given current rates of sea-level rise.

After many years of rigorous research and collaboration, USGS scientists and Blackwater NWR staff identified a target elevation that will support the growth and development of *S. patens* and *S. americanus*. In 2016, the refuge plans to artificially add sediment to raise the

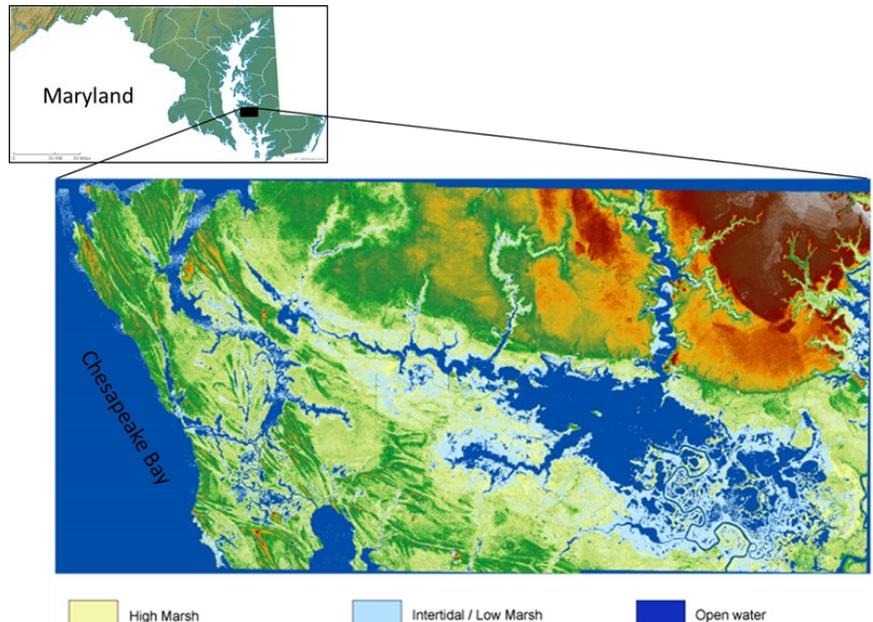


Figure 2. LIDAR image of the Blackwater NWR highlighting low elevation marsh habitat susceptible to degradation and conversion to open water (March 25, 2002; contour interval 30 cm; datum NAVD 88; after Larsen et al. 2004, USGS Open File Report 04-1302).



Figure 3. Rod surface elevation table at Blackwater National Wildlife Refuge, MD. Photo credit: James Lynch (USGS)



Figure 4. Marsh organ planted with *Spartina* species. Photo credit: Gregg A. Snedden (USGS)

level of the marsh surface to an elevation above the critical minimum sufficient for the production of these requisite plant species. This new management strategy should maximize plant belowground production, mitigate sea-level rise vulnerability, and enhance overall wetland stability.

According to the Blackwater NWR staff, USGS data have informed and reformed their management decisions greatly. Prior to this research effort, the goals and visions of the Blackwater NWR Comprehensive Conservation Plan were based on the best science available, but without a clear understanding of the mechanisms influencing habitat conversion on the refuge. The long-term partnership between the USGS and the USFWS at the Blackwater National Wildlife Refuge has resulted in the production of

essential datasets describing the processes contributing to wetland loss and the development of management strategies to slow or reverse these trends and enhance favorable waterfowl habitat.

For more information, contact [Nicole Cormier](#).

Further readings:

[The Blackwater NWR inundation model. Rising sea level on a low-lying coast: land use planning for wetlands](#)

[Do annual prescribed fires enhance or slow the loss of coastal marsh habitat at Blackwater National Wildlife Refuge?](#)

[Chesapeake Marshlands NWR Complex Comprehensive Conservation Plan](#)

[Feedbacks between inundation, root production, and shoot growth in a rapidly submerging brackish marsh](#)

[Response of salt-marsh carbon accumulation to climate change](#)

[The impact of sea-level rise on organic matter decay rates in Chesapeake Bay brackish tidal marshes](#)

[Temperature sensitivity of organic-matter decay in tidal marshes](#)

[Response of plant productivity to experimental flooding in a stable and submerging marsh](#)

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



Leaf to Landscape: Understanding and Mapping Forest Vulnerability to Hotter Droughts

“Hotter droughts” (also called “global-change-type droughts” or “hot droughts”) are an emerging but poorly-understood climate-change threat to forests worldwide. USGS scientists and their collaborators are using California’s recent hotter drought (2012-2015) as a preview of the future, gaining the information needed to help forest managers adapt to a warming world.

Background and need

We usually think of droughts as periods of low water supply (precipitation), but often overlook the other side of the equation: atmospheric water demand (the drying power of the atmosphere). For example, if we look only at precipitation records, California’s recent drought would rank as severe but not unprecedented; comparable periods of low precipitation occurred during the dust bowl era of the 1920s and 1930s. However, compared to the dust bowl era, temperatures during the 2012-2015 drought averaged about 1° C warmer, which significantly increased the atmosphere’s evaporative demand for water and easily made this the most severe drought in California’s 120-year instrumental record, and perhaps much longer. Additionally, water supplies for California’s cities, agriculture, industry, and forests all depend on the accumulation of a thick mountain snowpack each winter, which then melts and slowly releases water during the otherwise dry summer months. But the higher temperatures of the recent drought meant that virtually no snow accumulated during the winter, and the little bit that did accumulate melted far earlier than usual in the spring.

The effects of California’s drought on forests, particularly in the Sierra Nevada mountain range, have been extreme. U.S. Forest Service experts have estimated that, by the summer of 2015, tens of millions of trees had died, most of them in lower-elevation forests (Figure 1). Virtually no species has been spared, with substantially elevated mortality recorded in pines, firs, incense cedars, and oaks. A glaring exception has been the iconic giant sequoias; only a handful of sequoias have died, and those that died usually already had fire scar damage at their bases, which likely reduced their ability to transport



Figure 1. California’s hotter drought has already killed millions of trees, particularly in low-elevation forests. (Photo credit: N. Stephenson, USGS)

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the “Subscribe” button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



water to their crowns. But even though most sequoias have survived the drought, many have experienced unprecedented foliage die-back (Figure 2). By systematically shedding their older leaves, sequoias have conserved water by reducing the leaf area that is exposed to the drying power of the atmosphere.



Figure 2. Giant sequoias have fared better than other tree species, but many have shown unprecedented foliage dieback in response to the drought. (Photo credit: N. Stephenson, USGS)

If Earth continues to warm as projected, forests will experience hotter droughts that are both more frequent and more severe. Fortunately, managers are not helpless in the face of such changes; they can increase forest resistance to (ability to survive) hotter droughts. For example, forests can be thinned – usually by prescribed fire or mechanical thinning that selectively removes smaller trees – to reduce competition for water among the remaining trees. But the task is so vast that forest managers must perform triage, deciding where on the landscape their limited funds will be best applied. They thus need reliable forest vulnerability maps to help them strategically target their treatments, and to help them plan appropriate responses to future forest die-offs in highly vulnerable areas that they are not able to treat.

The Leaf to Landscape project

Using California’s hotter drought as a potential preview of the future, USGS Climate Research & Development Program scientists, working with a number of collaborators and stakeholders, have helped catalyze the Leaf to Landscape project. Leaf to

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the “Subscribe” button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



Landscape has two broad, complementary goals. First, it aims to provide empirically-derived maps of forest vulnerability to hotter droughts for large parts of California, letting the trees themselves reveal which parts of the landscape are most and least vulnerable. Second, it aims to improve our basic mechanistic understanding of forest vulnerability to hotter droughts, providing the grist for models with applications well beyond California.

To reach these ends, Leaf to Landscape has three main components, designed to be integrated across scales – from tree leaves to entire forests. The first is tree physiology during drought, spanning about 10 dominant species. Individual trees are climbed by professional climbers, and small branches are cut from high in their crowns (Figure 3). Back on the ground, one or more small branches are immediately

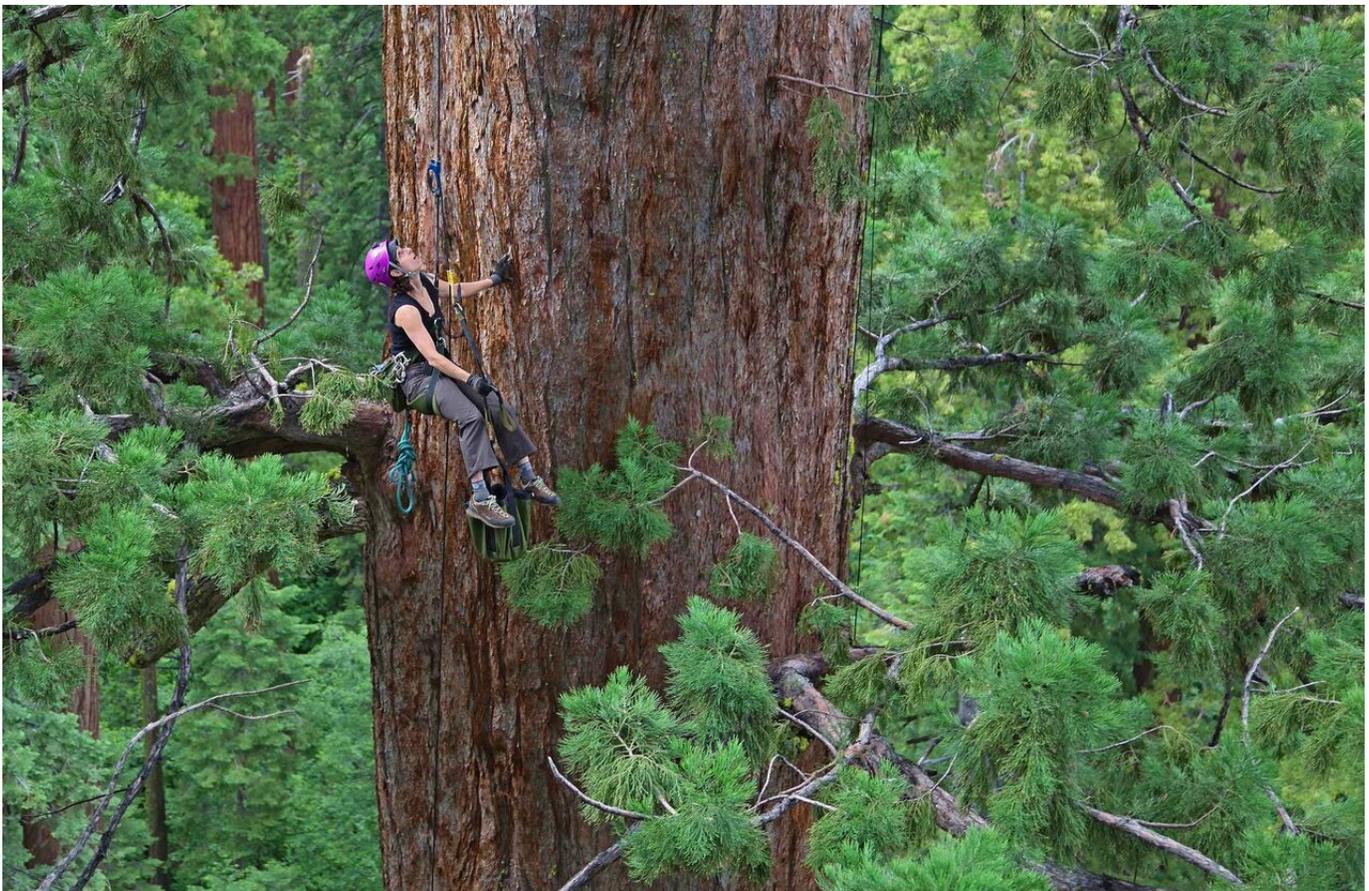


Figure 3. A University of California, Berkeley scientist climbs a giant sequoia to sample branches from high in its crown. (Photo credit: A. Ambrose, UC Berkeley)

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



inserted in a pressure chamber to quantify the degree of drought stress experienced by each tree (Figure 4). The remaining branch samples are then transported to a laboratory where leaf water content and other chemical markers – which together can provide insight into a tree’s level of drought stress – are quantified.

These measurements of drought physiology are strategically co-located with the second component of Leaf to Landscape: tree population monitoring. USGS maintains the world’s longest annual-resolution forest dynamics dataset, having annually tracked the health and fate of each of some 30,000 trees for up to 34 years (Figure 5).



Figure 4. A pressure chamber is used to record how much pressure is required to squeeze water out of a small sequoia branch – a measure of the drought stress experienced by the sequoia. (Photo credit: A. Ambrose, UC Berkeley)



Figure 5. USGS biologists assess the health of a white fir, one of tens of thousands of individual trees whose fates have been tracked annually throughout the drought. (Photo credit: USGS)

These data provide an invaluable long-term baseline of forest health, dynamics, and agents of tree mortality during “normal” forest conditions. Continued monitoring throughout the drought provides key information on the timing and proximate causes of tree mortality. Adding to these data, foliage dieback in giant sequoias is now monitored annually.

Both of the preceding components – tree drought physiology and population monitoring – provide essential calibration and validation for the third component: remote sensing (Figure 6). Remote sensing allows scientists to map forest drought responses over broad landscapes. High-resolution LiDAR is used to create a detailed three-dimensional map of

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the “Subscribe” button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



Figure 6. An aircraft captures high-resolution LiDAR and hyperspectral images of forests during the drought. (Photo credit: G. Asner, Carnegie Institute of Science)

tree crowns for millions of trees. The spectral reflectance of each tree crown is also recorded, allowing identification to species and measurement of whole-crown water content (Figure 7) and chemical signatures (such as nitrogen and non-structural carbohydrates) that may be related to tree health and drought stress.

The Leaf to Landscape project has successfully completed all three of these data collection components during its first full year. Reflecting the interdisciplinary nature of the work, funding and in-kind

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



contributions came from USGS, the National Park Service, the U.S. Forest Service, Stanford University/ Carnegie Institute of Science, and the University of California, Berkeley.

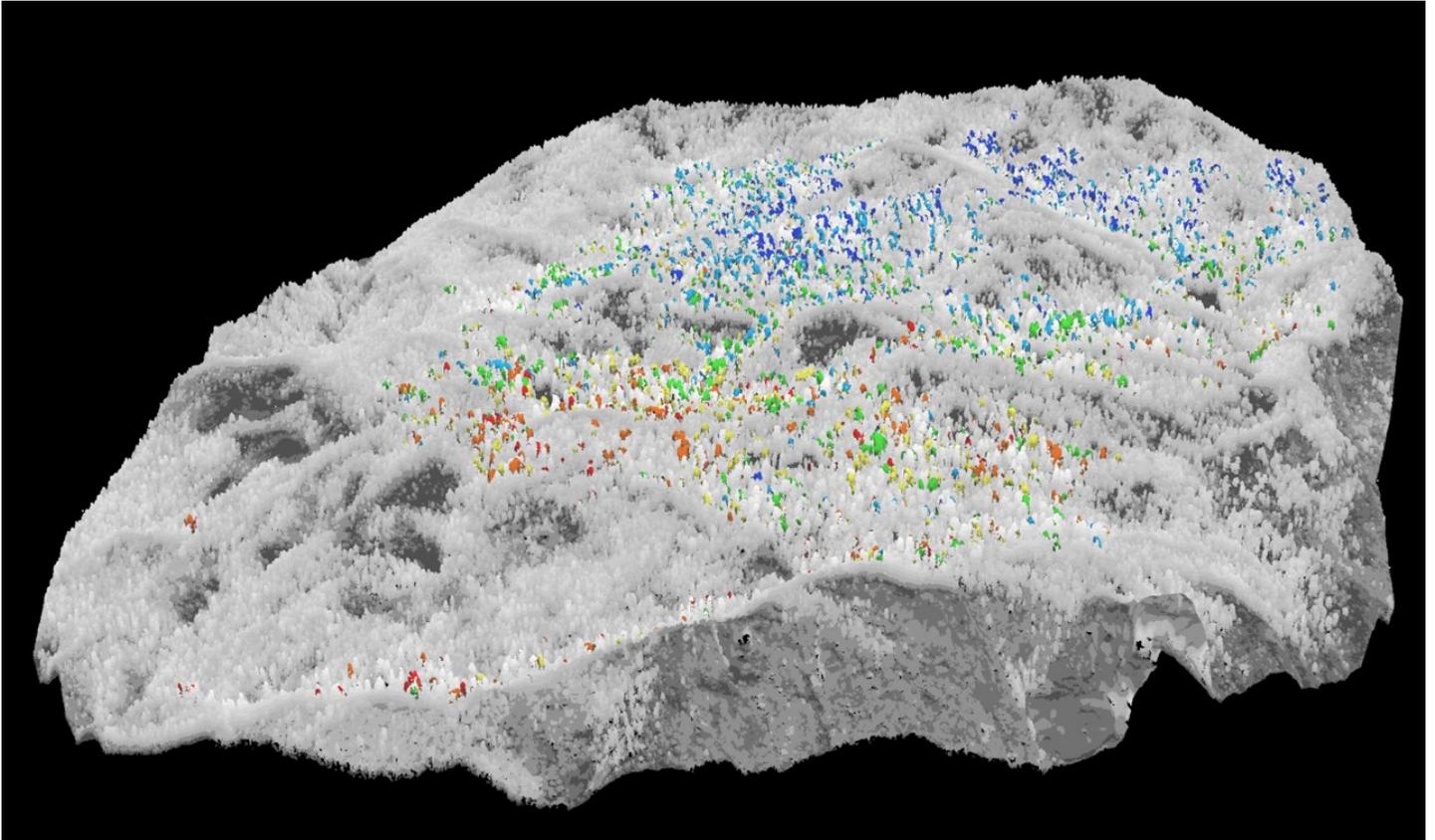


Figure 7. Remote imagery reveals a pronounced spatial gradient in the whole-crown water content of individual giant sequoias during the drought. Warmer colors indicate lower water content. (Credit: G. Asner, Carnegie Institute of Science)

Data analyses are underway, but early results from giant sequoias may give hints of findings to come. Remote sensing reveals substantial spatial variation in sequoias' whole-crown water contents (Figure 7). In contrast, direct ground-based measurements show very little spatial variation in sequoias' leaf water content or drought stress. The apparent paradox might be explained by spatial variation in whole-crown leaf area; that is, sequoias might maintain favorable water status by adjusting their total leaf area. Low leaf area could reflect responses to acute drought (i.e., sequoias abruptly reduce their leaf area by shedding older foliage) and/or long-term adjustments to sites with chronically low water supplies (i.e., sequoias never develop a large total leaf area). Much work remains to be done, but, at least for sequoias, total crown water content during the current drought might prove to be an indicator of site vulnerability to hotter droughts of the future.

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



Future directions

Fortunately, California is poised to get some relief from its crippling drought. Sea-surface temperatures in the tropical Pacific reflect one of the strongest El Niño events in the historical record, and strong El Niños typically bring heavy precipitation to most of California.

Even if the current El Niño is followed by several more wet years, thus signaling the end of the drought, the Leaf to Landscape project's efforts to understand forest vulnerability to hotter droughts will continue, especially to document and understand lagged drought effects and forest recovery. For example, anecdotal accounts suggest that tree mortality remains elevated for one or more years following drought. Leaf to Landscape will quantify the magnitude and duration of lagged tree mortality, and will determine the agents contributing to it (such as insects and pathogens). The project will also document the rate and magnitude of tree crown recovery – leaf area, water content, and chemistry – and interpret its relationship to tree growth and mortality.

The team will also complete maps of forest vulnerability for large sections of California, passing the information to land managers and helping with interpretation. The Leaf to Landscape project promises to improve our basic understanding of an emerging climate change phenomenon, with broad implications and applications.

For more information, contact [Nate Stephenson](#)

Further reading:

Allen, C. D., D. D. Breshears, and N. G. McDowell. 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. *Ecosphere* 6(8):129. <http://dx.doi.org/10.1890/ES15-00203.1>

Anser, G. P., P. G. Brodrick, C. B. Anderson, N. Vaughn, D. E. Knapp, and R. E. Martin. 2016. Progressive forest canopy water loss during the 2012–2015 California drought. *Proceedings of the National Academy of Sciences* (in press).

Diffenbaugh, N. S., D. L. Swain, and D. Touma. 2015. Anthropogenic warming has increased drought risk in California. *Proceedings of the National Academy of Sciences* 112(13): 3931-3936.

Millar, C. I., and N. L. Stephenson. 2015. Temperate forest health in an era of emerging megadisturbance. *Science* 349:823-826.

Williams, A. P., R. Seager, J. T. Abatzoglou, B. I. Cook, J. E. Smerdon, and E. R. Cook. 2015. Contribution of anthropogenic warming to California drought during 2012-2014. *Geophysical Research Letters* 42, doi:10.1002/2015GL064924.

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor

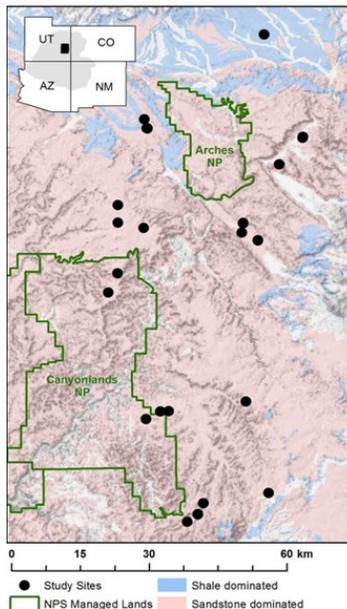


Plant responses to drought on the Colorado Plateau

Drylands cover 41% of the Earth's terrestrial land surface and are one of the most vulnerable regions to climate change. These ecosystems are already water-limited, and most dryland plant communities live near their environmental limits. Therefore, relatively small changes in water availability may lead to large ecological change. Currently, it is unknown whether these ecosystems can keep pace with modeled rates of climate change.

Over the next century, climate models project an increase in two types of drought: chronic but subtle "press-droughts" and shorter-term but extreme "pulse-droughts." Alone or combined, both types of droughts have the potential to push plants beyond key thresholds, leading to reduced growth or even mortality. Identifying which plants are most sensitive to drought is paramount to predicting the future of these regions.

The Colorado Plateau is a dryland ecosystem in the southwestern U.S. that models suggest could experience press-drought conditions by 2100 due to a 20% decrease in annual precipitation and a 6 °C increase in temperature. To examine the ecosystem consequences of such conditions, scientists funded by the USGS Climate Research & Development Program established a network of 40 rainout shelter sites in southeastern Utah. The study sites span a wide range in plant communities, soil types, and geologic substrates common to this region. Each site consisted of a shelter with clear v-shaped gutters to reduce precipitation by 35% to simulate the combined effects of decreased precipitation and increased temperature and a control plot receiving normal rainfall. The scientists examined the drought sensitivities of four plant functional types that differed in life form (grass vs. shrub) and photosynthetic pathway (C_3 vs. C_4) over a four-year period.



Left: Map of study sites, represented by black dots. Within the Colorado Plateau (gray shaded area on inset map), sites were selected to represent a wide range of plant communities, soil types and geologic substrates. Right: Example of the rainout shelters utilized in the study. The shelters impose year-round drought by reducing precipitation 35%. Each shelter is paired with a control plot (not shown) with similar vegetation but receiving normal rainfall. Photo credit; Adam Kind (USGS).

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



During the course of the press-drought experiment, a natural pulse-drought occurred, providing the researchers with an opportunity to examine the additive effects of these two drought types. The results revealed that, in this region, C₃ grasses are the most sensitive plant functional type to drought, C₃ shrubs are the most resistant, and C₄ grasses and shrubs have intermediate drought sensitivities. C₃ grasses were predicted to be the most vulnerable plant functional type to drought. However, the discovery that C₄ shrubs were more sensitive than C₃ shrubs was unexpected, given the higher water use efficiency of the C₄ photosynthetic pathway. Furthermore, the additive effects of press- and pulse-droughts caused high mortality of the C₃ grasses.

The results from this study have important ecological and economic ramifications for the Colorado Plateau. First, C₃ grasses are a primary food source for domestic livestock and many native herbivores. A loss of this plant functional type may have large impacts on local food webs as well as regional livestock operations. Second, the unexpected vulnerability of the C₄ shrubs suggests that plant functional types defined by life form and photosynthetic pathway may not sufficiently predict drought sensitivities. Finally, this study highlights the importance of the additive effects of press- and pulse-drought, particularly when species are living near their environmental limits.

The paper, *Pulse-drought atop press-drought: unexpected plant responses and implications for dryland ecosystems*, was published in *Oecologia*. It is available at <http://link.springer.com/article/10.1007/s00442-015-3414-3>

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor

[Jack McGeehin](#), Editor



Effects of land use on wetland greenhouse gas fluxes and soil properties

Wetland and grassland ecosystems throughout the central United States have largely been lost or degraded by anthropogenic activities such as drainage and agricultural production. Wetlands provide multiple environmental benefits to society, including wildlife habitat, floodwater storage, and enhancement of atmospheric carbon sequestration. Projections for future global climate change have led to efforts to identify strategies for mitigating rising concentration of atmospheric greenhouse gases (GHG). Among the strategies being considered is the sequestration of atmospheric carbon in soils through cessation of agricultural activities and subsequent restoration of natural ecosystems



Prairie Pothole Region wetlands represent a wide variety of wetland classes and sizes, and can be found in high densities. Photo credit: U.S. Geological Survey, Northern Prairie Wildlife Research Center, 17 July 2009

such as wetlands. Restoration of croplands also may reduce fluxes of nitrous oxide (N_2O), a powerful GHG which can be produced following the application of nitrogen-based fertilizers. However, the same conditions in wetlands that promote carbon sequestration in soils also can be conducive for the production of the GHG methane (CH_4). Thus, there are concerns that increased CH_4 fluxes may offset the benefits of carbon sequestration.

The Prairie Pothole Region (PPR), located in the northern Great Plains of North America, is characterized by millions of relatively small, mineral-soil wetlands dispersed throughout the agriculture-dominated landscape. Much of the PPR landscape was drained for agriculture during the 20th century, but restoration activities began in the 1980's to enhance ecosystem services such as GHG sequestration. However, there is a high degree of uncertainty regarding the impact of restoration on the overall GHG balance of these highly variable systems.

A comprehensive, 4-year study funded by the USGS Climate Research & Development Program was conducted on 119 PPR wetland catchments distributed among the major land uses of the region. Samples

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



of GHG fluxes, as well as soil moisture and temperature measurements, were collected every two weeks using static chambers. At the beginning of the study, samples of the soils near each gas-sampling location also were collected and analyzed for nutrients and physical properties. This study was designed to estimate the effects of land use on GHG fluxes and soil properties, and assess the overall efficacy of wetland restoration for the mitigation of atmospheric GHGs.

Results from the study showed that land use had significant effects on GHG fluxes and soil properties, with spatial variability reflecting factors such as landscape position (wetland, upland), wetland classification, geographic location, climate, and agricultural practices. The study also showed that soil organic carbon is lost when relatively undisturbed catchments are converted for agriculture. The rate of soil carbon sequestration after restoration, however, was highly variable, and carbon concentrations of restored and agricultural sites often were similar. In the PPR, some wetlands in a cropland setting are drained, while others are left relatively intact and simply embedded in agricultural fields. Fluxes of CH₄ from restored non-drained wetlands were similar to their cropland analogue, while CH₄ fluxes of restored drained wetlands were higher than drained cropland sites. This observation indicates that it is important to consider the type of wetland restoration (drained, non-drained) when assessing the overall balance between carbon sequestration and CH₄ fluxes. Results also suggest that N₂O fluxes were greatest in cropland catchments, and that these fluxes likely would be reduced through restoration.

The overall variability demonstrated by this study was consistent with other wetland investigations and underscores the difficulty in quantifying the GHG balance of wetland systems.

The paper, *Effects of land use on greenhouse gas fluxes and soil properties of wetland catchments in the Prairie Pothole Region of North America*, was published in *Science of the Total Environment*. It is available at <http://dx.doi.org/10.1016/j.scitotenv.2015.06.148>

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



Hydrologic response to climate change in the Las Vegas Valley

The city of Las Vegas was founded in the mid-19th century near a series of spring-fed meadows for which the city was named. These meadows, or “wetlands,” provided a continuous source of water to early residents, allowing them to survive and ultimately flourish in an otherwise harsh desert landscape. In prehistoric times, the wetlands were more extensive and covered much of the valley. Between ~100,000 and 10,000 years ago, for example, wetlands dotted the desert landscape throughout southern Nevada’s Las Vegas Valley, attracting a plethora of Ice Age animals, including mammoth, sloth, bison, camel, horse, dire wolf,



In southern Nevada, fine-grained buff-colored deposits lie in the valley against the backdrop of the Las Vegas Range just outside the city limits of Las Vegas. Once thought to be remnants of a large lake, these deposits actually record the presence of extensive wetlands that responded dynamically to past episodes of abrupt climate change. Photo credit: Eric Scott, Dr. John D. Cooper Archeological and Paleontological Center

and even American lion and sabre-toothed cat. Although the extent of the wetlands has decreased significantly since the end of the Pleistocene, the valley remains home to numerous species of water birds, reptiles, and mammals. New research examines the long-term history of these deposits to determine the sensitivity of desert wetlands to climate change, as well as to constrain the magnitude of hydrologic variability before 20th century urbanization and human alteration of the landscape.

Desert wetlands coalesce where groundwater breaches the surface and provide otherwise dry and barren landscapes with stable water supplies that underpin unique ecosystems that support spring-dependent species. Within these settings, sediments transported by water and wind are trapped by a combination of wet ground conditions and dense plant cover. Over time, the sediments build up and are ultimately preserved in the geologic record as “paleowetland deposits.” These deposits contain information on the

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the “Subscribe” button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



timing and magnitude of past changes in water table levels and, therefore are an important source of information on past variations of climate and hydrology.

Recently, scientists funded by the USGS Climate Research & Development Program, published the first in a planned series of scientific papers that utilized geological mapping, stratigraphic analysis, and radiocarbon dating to reconstruct a detailed history of ebb and flow for paleowetlands in the Las Vegas Valley. The results of the study reveal that the wetlands expanded and contracted in virtual lock step with climate variations recorded in Greenland ice cores and records from the western United States over the past 35,000 years or so. Most dramatically, the valley's entire wetland system collapsed multiple times during this interval when conditions became too warm. Drought-like conditions in the valley, as recorded by widespread erosion and the formation of desert soils, typically lasted for a few centuries, illustrating the potential vulnerability of these fragile ecosystems to climate change.

Wetlands are an invaluable resource for flora and fauna in arid environments worldwide and serve as keystone ecosystems that support a high species biodiversity including endemic, threatened, and endangered biotas. The unique geological lens afforded by wetland deposits provides a valuable context when planning for the potential response of these fragile ecosystems to future climate warming.

The paper, *Dynamic Response of Desert Wetlands to Abrupt Climate Change*, was published in the *Proceedings of the National Academy of Sciences USA*. It is available at <http://www.pnas.org/content/112/47/14522>.

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



Climate change and coastal wetlands: the importance of temperature and rainfall regimes

Coastal wetlands are highly-productive and valuable ecosystems. In addition to providing habitat for many fish and wildlife species, coastal wetlands store carbon, provide food, improve water quality, protect coastlines, support coastal fisheries, and provide recreational and tourism opportunities. However, due to their position at the land-sea interface, coastal wetlands are vulnerable to many of the impacts that accompany a changing climate. As a result, resource managers and other decision makers are increasingly challenged to prepare for future change in a way that ensures healthy coastal wetlands.



A freeze sensitive mangrove-marsh transition zone in Cedar Key, FL. Photo credit: Michael Osland (USGS)

Across the globe and in all ecosystems, macroclimatic drivers such as temperature and rainfall regimes govern ecosystem structure and function. Macroclimatic drivers have been the primary focus of climate change-related threat evaluations for terrestrial ecosystems, but they have been largely ignored for coastal wetlands. Climate change vulnerability assessments for coastal wetlands have generally focused solely on sea-level rise impacts (e.g., inundation) without considering other important aspects of climate change.

In a recent publication, scientists funded by the USGS Climate Research & Development Program have demonstrated the importance of incorporating macroclimate drivers into climate change vulnerability assessments for coastal wetlands.

Results of the study show that the southeastern United States is an excellent place to illustrate the global importance of temperature and rainfall regimes upon coastal wetland ecosystems. Coastal wetlands are abundant in this region; approximately eighty percent of the coastal wetlands in the contiguous United States are located in the southeastern portion of the country. From a macroclimatic perspective, this

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page. If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



region is especially sensitive because these abundant coastal wetlands continuously span two climatic gradients (i.e., a rainfall gradient and a winter severity gradient) that greatly influence coastal wetland ecosystem structure and function and the supply of ecosystem goods and services. In hot and wet climates, mangrove forests (woody plants) are dominant. However, mangroves can be killed or damaged by extreme freeze events. So, in cold and wet climates, salt marsh grasses, sedges, and rushes are dominant. In dry climates, conditions often are too salty for plants; so, coastal wetlands in arid climates are often unvegetated salt flats.

In the future, changes in the frequency and intensity of extreme freeze events could lead to the poleward migration of mangrove forests at the expense of salt marshes in Texas, Louisiana, and parts of Florida. In drier regions (that is, south and central Texas), changes in freshwater availability are expected to result in changes in the abundance of coastal wetland foundation plant species. Such changes will affect some of the goods and services provided by these ecosystems. The intent of this research is not to minimize the importance of sea-level rise. Rather, the overarching aim is to illustrate the need to also consider macroclimatic drivers within vulnerability assessments for coastal wetlands.

The paper, *Beyond Just Sea-Level Rise: Considering Macroclimatic Drivers within Coastal Wetland Vulnerability Assessments to Climate Change*, was published in *Global Change Biology*. It is available at: <http://onlinelibrary.wiley.com/doi/10.1111/gcb.13084/abstract>

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



Landscape Effects of Oil and Gas Development

Relatively new deep well drilling technology, such as is currently utilized in hydraulic fracturing (“fracking”), has created an economic boom in the market for hydrocarbons. Previously untapped deposits of oil and natural gas can now be accessed in areas that include the Marcellus and Utica Shale deposits in the east and the Bakken Formation in Montana and the Dakotas.

While there are many environmental concerns associated with fracking, one of the often overlooked issues is the effect that these practices have on the landscape. Ecosystems and the services that they provide are largely affected by the spatial arrangement of energy development on the landscape. Fracking, and hydrocarbon development in general, results in surface disturbance from drill pads, roads and pipelines that alter landscape dynamics and habitat characteristics such as forest edge and forest interior area. Figure 1 shows an example of a forested area in Pennsylvania with high oil and gas development activity.

To study this effect, scientists funded by the USGS Climate Research & Development Program extracted features of landscape disturbance related to hydrocarbon development from high-resolution aerial photographs in the Marcellus Shale region of Pennsylvania for the period of 2004 – 2010. Using geographic information system (GIS) technology and ancillary data from state databases, disturbance features were mapped and statistically summarized.

Results show that the disturbance from the newer hydraulic fracturing activity, termed “Unconventional Oil and Gas,” is only part of the landscape change story in Pennsylvania. Conventional oil and gas wells, which are also prevalent and have a long history in Pennsylvania, receive

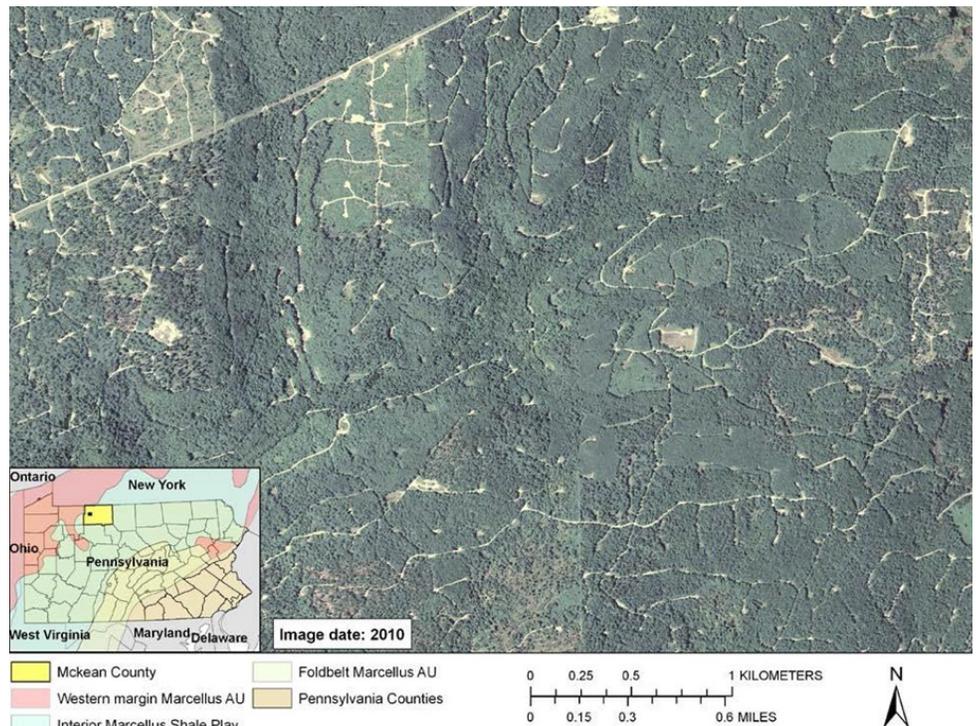


Figure 1. A forested landscape in McKean County Pennsylvania showing the disturbance pattern from mostly conventional hydrocarbon development (from Slonecker and Milheim, 2015).



far less scientific attention and account for more landscape disturbance than their unconventional counterpart (Figure 2). Other important results from this research effort include the discovery that some form of landscape disturbance related to conventional or unconventional oil and gas development occurred in approximately 50% of the 930 watersheds studied. This development was closer to streams than the state-defined recommended safe distance of 100 feet in approximately 50% of the watersheds. Landscape disturbance was in some places closer to impaired streams and wildland trout streams than the recommended safe distance and occurred in approximately 10% of exceptional value watersheds. Disturbance tended to occur at interior forest locations, which are critical for some plant and animal species, and occurred in approximately 30% of the watersheds with resident populations defined as disproportionately exposed to pollutants.

The paper, *Landscape Disturbance from Unconventional and Conventional Oil and Gas Development in the Marcellus Shale Region of Pennsylvania, USA*, was published in *Environments*. It is available at: <http://www.mdpi.com/2076-3298/2/2/200>

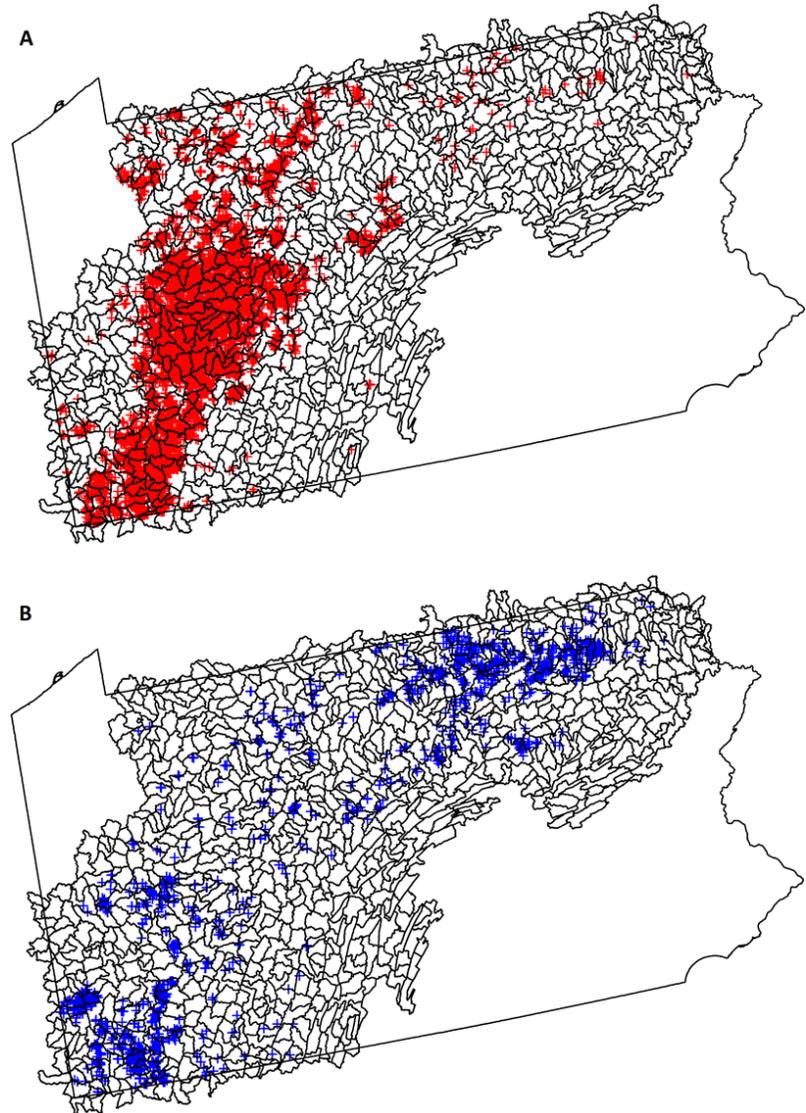
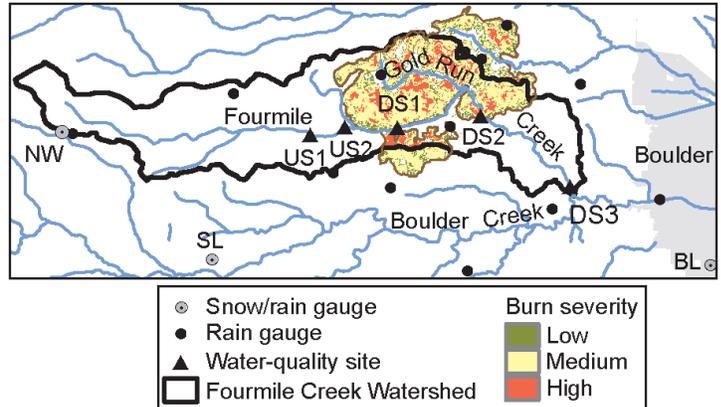


Figure 2. Location of conventional (A) and unconventional (B) oil and gas developments sites. Site are displayed as points (modified from Slonecker and Milheim, 2015).



Fires, floods, and the future of water supplies in the southwestern U.S.

About half of the water supply in the southwestern U.S. is derived from forested land, which generally yields higher quality water than any other land use (such as agriculture or urbanized land). However, forests are vulnerable to wildfire: in the southwestern states of Colorado, New Mexico, Arizona, and Utah, more than 12 million acres of land (nearly 5% of total area), including important forested water-supply watersheds, have burned in the past 30 years. Wildfires increase the susceptibility of watersheds to both flooding and erosion, which can lead to short- and long-term impairment of water supplies.



Map of the Fourmile Creek Watershed, showing burn severity for the Fourmile Canyon Fire, precipitation gauges, and sampling sites. (From Murphy et al., 2015)

Scientists funded by the USGS Climate Research & Development Program, the [USGS Water Mission Area](#), and the [Boulder Creek Critical Zone Observatory](#) collected streamflow and water-quality data for three years after the 2010 Fourmile Canyon Fire in Colorado, in a geographic setting typical of the American Southwest. They then compared the results with data from a high-density rain gage network to assess the role of precipitation type, intensity, and spatial distribution on concentrations and yields of stream constituents that are often elevated after wildfire: total suspended solids, nitrate, dissolved organic carbon, and manganese.

The researchers observed that for three years after the wildfire, water quality downstream of the burned area substantially deteriorated in response to commonly occurring local thunderstorms. Suspended sediment, dissolved organic carbon, nitrate, and manganese concentrations were 10-156 times higher downstream of the burned area than upstream, reaching concentrations that could impair the ability of water-treatment plants to effectively treat water for human consumption.

Results from this study quantitatively demonstrate that wildfire can affect downstream water quality for several years, even in a watershed that was only 23% burned. Climate models forecast the potential for future increases in wildfire frequency and size in the southwestern U.S., as well as more frequent and intense storms. These could result in more common wildfire impacts on water quality, intensifying water supply and quality problems related to projected decreases in runoff and continued population growth. The study suggests several potential adaptation strategies to minimize the introduction of problematic constituents into water-treatment facilities or reservoirs after wildfire. One such strategy involves the

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor
[Jack McGeehin](#), Editor



development of real-time monitoring networks to provide advanced warning to water treatment facilities of high-intensity rainfall and flooding events that have the potential to impair water quality. Water-treatment plants could then close intakes during the event and/or use alternate sources.

The paper, *The Role of Precipitation Type, Intensity, and Spatial Distribution in Source Water Quality after Wildfire*, was published in Environmental Research Letters. It can be found at <http://dx.doi.org/10.1088/1748-9326/10/8/084007>

Climate Matters is produced by the U.S. Geological Survey Climate Research and Development Program. All content is copyright free, and can be reprinted without permission.

Comments, feedback, and suggestions for future stories are welcome. This and past issues are available on the [Program Newsletter](#) page.

If you would like to subscribe please click the "Subscribe" button on the [Program Newsletter](#) page.

[Debra Willard](#), Managing Editor

[Jack McGeehin](#), Editor