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An Evolving Research Agenda at the Marcell Experimental Forest

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Introduction

The Marcell Experimental Forest (MEF) was established to study the effects of forest management on watershed dynamics in upland–peatland landscapes. We are not aware of any other research location that has the depth and breadth of data from these landscapes (Chapter 2). Findings from 50 years of research constitute a foundational knowledge of the hydrology and biogeochemistry of peatland watersheds (Table 3.1). In this chapter, we discuss what historically and currently drives our research program, the importance of networks in our research portfolio, summarize our past and current research, assess what expert panels anticipate are important future research topics, and align our expectations of future research at the MEF.

Drivers of Research at the MEF

The evolution of research at the MEF is similar to that for other watershed studies throughout the USDA Forest Service's network of experimental forests and ranges. Experimental forests with gaged watersheds were established to assess the impact of forest management on water (Holscher 1967).

TABLE 3.1

Time Series of Research Themes on the MEF

1960s	
	Increasing lowland forest productivity
	Understand peatland hydrology, water and energy budgets, peat soil properties
1970s	
	Determining harvesting effects on water quality and quantity
	Hydrologic modeling of peatland watersheds
1980s	
	Effects of atmospheric deposition and ecosystem acidification
	Methane production from peatlands
	Biogeochemistry of carbon and nutrients
1990s	
	Net ecosystem exchange of carbon in peatlands
	Hydrologic cycling of mercury and organic carbon
2000s	
	Hotspots of biogeochemical activity in peatland landscapes
	Controls on mercury methylation
	Hydrologic source areas of water and solutes

Initial studies at the MEF measured hydrological response to clearcut harvests of upland and peatland forests (Chapter 13). Funding was mainly congressionally appropriated to the Forest Service and there was little pursuit of extramural funding for research. In addition to personnel, instrumentation, and study costs, Forest Service funding was used to support collaborative research agreements with academic and other agency scientists. Beginning in the 1970s with the Clean Water and Clean Air Acts, the focus of many Forest Service watershed experimental forests shifted to research on biogeochemical cycling and the effect of acid rain on terrestrial and aquatic systems. The Clean Air Act also was the impetus for establishing the National Atmospheric Deposition Program (NADP) in the late 1970s and the Mercury Deposition Network (MDN) in the early 1990s. During the 1970s and 1980s, appropriated funds were sufficient to conduct directed research.

Since the late 1980s, research at the MEF and at other experimental forests has gravitated toward topics and projects that are supported extramurally, as real dollars (with consideration for inflation) for research have declined precipitously. As a result, scientists at most of the thriving experimental forests actively pursue extramural funding. Such pursuits are difficult because Federal scientists are not eligible to receive grants from some funding sources. Nevertheless, over the past decade, scientists at the MEF have received several grants, each in excess of US$1 million, from the Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE), as well as numerous smaller grants. This shift in funding sources has greatly expanded the audience served by Forest

Service Research and Development (R&D). Although the National Forest System still benefits from R&D study findings, the audience for our research findings has become more diverse, especially as the search for extramural funding expands research in new directions. Fortunately, this funding paradigm and the peer-review process ensure a research program that is directed toward compelling science. However, this new funding scenario taxes financial resources that are needed to measure and maintain long-term experiments. Currently, we invest our appropriated funds into the long-term measurements while we use extramural funding in short-term studies that answer specific questions, many times to better understand trends in long-term data and to develop science in emerging issues. However, based on current levels of appropriated funding, we are on the verge of needing to acquire extramural funding to maintain our long-term data collection.

Participation in Networks

One way for experimental forests to leverage their scientific potential is to share data with others via networks (Lugo et al. 2006). Well-designed networks allow examination of processes and responses across multiple ecosystems and varying scales. Scientific leaders at the MEF have long understood the value in contributing to and utilizing networks in our research. The MEF was one of three founding sites in the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) (Miller 1980) and the MEF NADP site has been a test site for new monitoring instruments since its establishment. In the early 1990s, the MEF also became one of the first sites in the NADP subnetwork that quantifies mercury deposition, the Mercury Deposition Network (MDN) (Vermette et al. 1992, 1995a,b). During this same time, the MEF also became a pilot site for testing methods for the Long-Term Soil Productivity Network (LTSP) (Tiarks et al. 1993), the goal of which is to determine the effects of compaction and removal of organic matter on forest productivity across the United States and Canada (Powers et al. 2005). In early 2000, cooperative efforts between the USDA and Oregon State University led to the hydrological (HydroDB) and climate (ClimDB) databases (http://www.fs1.orstedulclimhy). The MEF also will participate in a water-chemistry database (tentatively named StreamChemDB) that is under development through collaboration among the Forest Service, National Center for Air and Stream Improvement, and Oregon State University.

The MEF has recently become part of the National Phenology Network (NPN) (Betancourt and Schwartz 2005), EcoTrends Project Network (Moran et al. 2008), United States–China Carbon Consortium (USCCC) (http://research.eeescience.utoledo.edu/lees/research/usccc/), and an internal Forest Service Experimental Forest and Range (EFR) Synthesis Network

(Lugo et al. 2006). The NPN was established to advance our understanding of how the phenology of plants, animals, and landscapes responds to environmental variation and climate change, and how these responses affect processes and phenomena in the biosphere. The EcoTrends Project was designed to promote and enable the use of long-term data to examine trends in climate, land cover, and habitat availability with important consequences for plant, animal, microbial, and human populations. The USCCC was established as a collaborative consortium between American and Chinese institutions that are interested in the use of eddy covariance to determine the role of managed ecosystems in global carbon and water cycles. The EFR Synthesis Network comprises 18 Forest Service experimental forests that form a national platform to synthesize studies of forest management impacts on water, changing climate, atmospheric chemistry, and invasive organisms. The MEF was considered as a possible relocatable site in the National Ecological Observation Network for the Great Lakes (GLEON), although it was not chosen in the first round of selections. It is likely that MEF will participate in GLEON at some level in the future.

Past Research

While this book reviews past research findings at the MEF, it is helpful to briefly summarize the research that informs our current philosophy and sets a firm foundation of a future research agenda (Table 3.1). The MEF conducted the first paired-watershed studies to determine the effects of experimental vegetation manipulations on stream water yield and chemistry from upland–peatland watersheds (Bay 1970a). Various forest management practices and effects on stream water yield and water chemistry have been studied (Bay 1968; Ohmann et al. 1978; Verry 1996; Grigal and Brooks 1997; Chapters 13 and 14). Treatments to experimental watersheds include upland clearcutting of aspen (Verry 1972), peatland strip, and clearcutting of black spruce (Verry 1981), prescribed fire in a harvested fen peatland (Knighton and Stiegler 1981), upland nitrogen fertilization (Perala 1983; Berguson and Perala 1988), conversion of upland aspen to a conifer forest, and use of cattle grazing as an alternative to herbicide application (Chapters 12 and 14). Field data and model results have been used to evaluate the effects of forest management practices on water yield and bankfull stream flow (Guertin and Brooks 1985; Verry 1987; Barten and Brooks 1988; Lu 1994; Chapter 15), which informed the development of forestry best management practices (BMPs) in Minnesota and the region (Verry 2004; Chapter 7). These data are also included in interregional and international data syntheses to assess forest harvest effects on water yield (Hornbeck et al. 1993; Sahin and Hall 1996; Stednick 1996; Brown et al. 2005; Guillemette et al. 2005).

While completing graduate research in 1959, Don Boelter became one of the first organic-soil scientists in the United States. His research and subsequent studies in the 1960s and 1970s quantified water storage and flow through peatland soils in relation to the physical properties of organic soils (Boelter 1964a, 1965, 1966, 1968, 1969; Nichols and Boelter 1984) and laid the foundation for later studies of organic soils at the MEF (Gafni and Brooks 1986a,b, 1990; Malterer et al. 1987; Malterer et al. 1992; Chapter 5). Boelter's initial research applied lab techniques that typically were used for mineral soils to study the water content and matric potential of organic soils (Boelter 1964b, 1965). This work was followed by field studies (Boelter 1965, 1968, 1975) and ultimately scaled up to explore undrained peatland hydrology (Boelter 1974a), water table manipulations (Boelter 1972a), and peatland drainage at the watershed scale (Boelter 1972b, 1974b). This research on the physical properties of peat later was used to develop and calibrate hydrological models, particularly the Peatland Hydrologic Impact Model (PHIM) (Guertin 1984; Guertin et al. 1987; Brooks and Kreft 1989; McAdams 1993; Chapter 15).

Various aspects of watershed energy budgets have been examined, including the link between evapotranspiration and the physical properties of peat (Bay 1966; Nichols and Brown 1980), effects of harvesting on net radiation fluxes (Brown 1972), albedo above black spruce canopies (Berglund and Mace 1972, 1976), and clearcut strips (Brown 1972). Later research was extended beyond point measurements of evapotranspiration to larger spatial scales, e.g., entire peatlands (Verma et al. 1995; Chapter 6).

The data collected on upland and peatland water levels at the MEF constitute one of the longest running daily records of groundwater in the Lake States; they reveal hydrologic patterns that can be discerned only from long-term data. Notably, these data have characterized the influence of inter-decadal climatic variation on the regional groundwater table, and identified a surprising lack of synchrony between perched water table dynamics and the regional flow system (Bay 1967, 1970b; Nichols and Verry 2001; Chapters 2 and 13). Groundwater-well data from the MEF have been used to develop physical models of peatland hydrology (Sander 1976) and estimate deep seepage of groundwater from perched peatlands to the regional groundwater table (Nichols and Verry 2001; Verry 2003).

Over the decades, water, energy, and solute budgets have been calculated using the small-watershed approach by which major pools (e.g., soils and vegetation) and fluxes (precipitation inputs and watershed outfluxes) are measured (Chapters 7 and 8). Such watershed-scale mass balances have been published for hydrogen (Urban et al. 1987), dissolved organic carbon (Urban et al. 1989a; Kolka et al. 2001), major cations (Verry and Urban 1992; Urban et al. 1995), nitrogen (Urban and Eisenreich 1988; Verry and Urban 1992), phosphorus (Knighton and Stiegler 1981; Verry and Urban 1992), and sulfur (Urban et al. 1989b). To gain additional insight on the processes that control element pools and fluxes, biogeochemical transformations such as nitrification and denitrification (Urban and Eisenreich 1988), sulfate reduction, and sulfur reoxidation (Urban et al. 1989b) have been measured. In the field of mercury research, studies at the MEF have elucidated complex processes that affect the transport of mercury from atmospheric sources through the landscape (Kolka et al. 1999, 2001) and interactions among sulfur, organic carbon, and mercury (Skyllberg et al. 2000, 2006; Jeremiason et al. 2006; Mitchell et al. 2008a,b,c, 2009; Skyllberg 2008; Chapter 11).

Pioneering carbon-cycle studies at the MEF have formed a basis for our current focus on the effects of climate change on carbon storage in northern forest landscapes (Chapter 10). Quantifying sinks and sources of atmospheric carbon dioxide (CO_2) is an important area of carbon-cycle research at the MEF (Chapter 9), because storage of peatland carbon may become destabilized with climate change and potentially become a substantial source of CO_2 to the atmosphere, thus contributing to global warming. Previous studies have measured CO_2 fluxes using chamber and eddy covariance methods (Kim and Verma 1992), including the first use of eddy covariance during the early 1990s to measure methane and CO_2 emissions from peatlands (Kim and Verma 1992; Verma et al. 1992a,b, 1995; Clement et al. 1995). Data from the MEF and other northern Minnesota sites were the first to quantify methane emissions from natural peatlands (Harriss et al. 1985; Crill et al. 1988). The continually expanding data set from the MEF is included in regional and global scale assessments of methane emissions in peatlands (Shotyk 1988; Bartlett and Harriss 1993; Waldron et al. 1999; Wania et al. 2009). Several peatland landscape models have been developed that quantify the hydrological and biogeochemical processes controlling peatland carbon stores (Trettin et al. 1995, 2006; Zhang et al. 2002; Cui et al. 2005). Isotope studies of methane provide additional insight into the processes that control methane fluxes from peatlands (Quay et al. 1988; Stevens and Engelkeimer 1988; Kelly et al. 1992; Lansdown et al. 1992; Chanton et al. 1995; Hornibrook et al. 2000). A series of studies has measured environmental factors that control the spatial and temporal variability of methane emissions in peatlands (Dise 1992, 1993; Dise et al. 1993; Shurpali et al. 1993; Shurpali and Verma 1998; Dise and Verry 2001). Smemo and Yavitt (2007) documented anaerobic methane oxidation in freshwater wetlands. Studies at the MEF also have quantified the stabilization of organic carbon on soils (Fissore 2007; Fissore et al. 2008) and the hydrological transport of organic carbon from peatlands to downstream receiving waters (Gorham et al. 1985; Urban et al. 1989a; Kolka et al. 1999, 2001; Chapter 8).

Current Research

The current research agenda at the MEF builds on previous research and the monitoring legacy. Ongoing hydrological research is designed to determine how flowpaths through the landscape affect water and solute transport, and how vegetation change affects water yield. Studies have been initiated to determine how rainfall interception, evapotranspiration, and subsurface hydrology differ between the S2 control watershed and the S6 watershed, where the upland forest was converted from deciduous to conifer species in the 1980s (Chapter 13). To gain insight on the effect of various climate scenarios on the productivity of northern forests, we are exploring how climate variability and climate extremes affect annual tree growth in black spruce, aspen, and upland conifer stands.

Currently we have several major thrusts of carbon cycle research. In the last 3 years, we have reestablished the use of eddy covariance to measure CO_2 and methane at the Bog Lake fen, an open shrub, and grass fen. We hope to merge past data from studies in the 1990s with the current data to determine how peatland carbon pools and fluxes have changed at Bog Lake in the last 2 decades. We also measure soil respiration with an automated chamber system that analyzes samples from lawns, hummocks, and hollows in the immediate vicinity of the eddy covariance system, as well as a single chamber system that is deployed in the uplands of the S2 watershed.

In other carbon research, we also are exploring how dissolved organic matter (DOM) composition varies among hydrologic flow paths as well as the long-term trends of watershed total organic carbon (TOC) export. Stream TOC concentrations at the MEF have doubled since the 1980s (Chapter 8). Our long-term data sets are being used to assess the environmental or climatic factors that affect this increase. The studies of DOM composition are focused on characterizing the differences between peatland and upland sources that affect carbon, nitrogen, and mercury biogeochemical cycles.

A third major area of carbon research is aimed at scaling measurements to the landscape and regional scale (Bradford et al. 2009; Weishampel et al. 2009). Related research is assessing the influence on sample type and intensity, and distance between samples on scaling procedures for carbon pools and fluxes (Bradford et al. 2010). In 2009, a study was initiated to determine the decay rates of deadwood. Individual trees were cut in triplicate sites of aspen, red pine, and black spruce. Tree boles were propped up (simulating snags) or laid on the ground (simulating down woody debris) and cookies were cut to determine wood density at the time of felling. Future sampling over the next 20–30 years will allow us to determine decay rates.

We continue to build on the solid foundation of mercury-cycling research with four ongoing studies. In a large manipulative study on experimental and control areas, sulfate inputs were quadrupled across half of the S6 bog relative to ambient atmospheric deposition to study the effect of sulfate availability on methylmercury production (Jeremiason et al. 2006; Coleman-Wasik 2008; Chapter 11). Although the sulfate additions ended in 2008, we continue to monitor outflow and peatland pore waters for mercury to determine the rate of recovery. In a mesocosm study, enriched-abundance mercury isotope tracers were added along with various amounts of sulfate and different carbon sources (e.g., sugars and leaf-tissue leachates) to small chambers in a full factorial experiment to understand the controls on mercury methylation in peatlands. Other ongoing work integrates high-resolution topographic data from light detection and ranging (LiDAR) in a study of topographic controls on methylmercury production (Richardson et al. 2010, in press). In another new study, upland subsurface runoff will be collected to assess the effects of forest harvesting on methylmercury production through the use of small amounts of enriched-abundance isotope mercury tracers.

Past and current studies have contributed to our knowledge of biogeochemical hotspots in the landscape. Mitchell et al. (2008c) showed that the lagg zones along the bog edges where upland and peatland waters mix are biogeochemical hotspots for methylmercury production. Similarly, recently collected data show that lagg zones also are hotspots for the production of nitrous oxide, the possible result from denitrification.

Future Research at the MEF

Over the past decade, recommendations from blue ribbon panels on environmental science, hydrology, ecology, and climate change have identified a consistent set of research priorities. The National Research Council (2001) identified priorities in environmental research related to biogeochemical cycles, biological diversity and ecosystem functioning, climate variability, hydrologic forecasting, infectious disease and the environment, human uses of resources, land use and land cover change, and reinventing the use of resources (recycling). A subsequent panel assessed the state of knowledge about hydrologic consequences of changing forests and developed a list of 13 research needs for forest hydrology. The panel indicated the need to develop a landscape approach to forest hydrology, create a better understanding of the influence of forest disturbance, forest management, and climate change on water and chemical cycles, and to more fully understand cumulative watershed effects on water quality and quantity (National Research Council 2008).

The U.S. Geological Survey (2007) identified 10 year research priorities (2007–2017) that include understanding ecosystems and predicting ecosystem change, climate variability and change, and developing a nationwide water census. The National Science and Technology Council (2007) recommended research to support water availability and water quality. Priorities include identifying ways to use available water supplies more efficiently, developing and improving tools for water management, and also a national water census.

The Heinz Center, a nonprofit institution dedicated to improving the scientific and economic foundation for environmental policy, assessed the state of the nation's ecosystems in 2002 and 2008 (Heinz Center 2002, 2008). The assessment led to a report that identified data gaps that contribute to uncertainty in evaluating ecosystem health (Heinz Center 2006). The report listed 10 data gaps that related to key issues such as wetlands, remotely sensed land-cover data, human exposure to chemical contaminants (e.g., mercury in fish), nitrogen flows in rivers that produce hypoxia, ecosystem carbon storage, endangered and threatened species or communities, extent and impact of nonnative species, condition of plant and animal communities, condition of riparian areas and stream habitat, and use of groundwater levels to quantify groundwater depletion.

The Millennium Ecosystem Assessment (2005) recommended enhancing global monitoring networks to better assess trends in hydrology and land-use change, improve inventories of plant and animal species, provide greater understanding of drivers of ecosystem change at multiple scales, increase our understanding of nonlinear relationships in ecological processes that influence predicted thresholds of change, and collect additional data with which to evaluate ecosystem services, including the relationship between those services and human well-being.

A review by the U.S. Climate Change Science Program (USCCSP) identified 24 research needs (Lucier et al. 2006) in three categories: (1) feedbacks between ecological systems and climate change, (2) consequences of global change for ecological systems, and (3) sustaining and improving ecological systems in response to global climate change. The relevant research under (1) addresses how climate affects energy, water, and trace gas fluxes in terrestrial and aquatic ecosystems and how these changes will feedback on climate change. Changes would include perturbations to nitrogen and carbon cycles, effects on biological diversity and invasive species, and adverse effects on phenology, stomatal conductance, canopy growth, and albedo. The research questions under (2) include recommendations to better understand how changes in temperature and precipitation affect ecosystem carbon, water, and nutrient cycles and how those changes affect biological communities (e.g., aquatic food webs) in managed and unmanaged landscapes. Also included are questions related to ecosystem sensitivity and vulnerability to climate extremes, identifying processes and ecosystem types that are especially vulnerable to climate change or especially resilient, and how climate change affects ecosystem services. The research under (3) is directed at developing better management techniques at multiple scales that include considerations and trade-offs resulting from climate change. On the basis of these recommendations by the USCCSP, the National Research Council (2009) has recommended restructuring research on climate change in the United States, suggesting the development of a system that includes physical, biological, and social observations; a national assessment process to determine the risks and costs of climate change; and improved coordination among Federal agencies in providing tools for decision makers. In addition, recommendations include directed research aimed at better climate forecasting and understanding ecosystem vulnerabilities and their ability to adapt and mitigate climate change, and research focused on interactions among climate, human, and environmental systems.

When research priorities are reviewed, common themes center on how ecosystems respond to climate variability and change. Specifically, research is needed to understand how climate change affects carbon, nitrogen, and water cycles; biodiversity; spread of invasive species; and plant and animal phenology, and how changes in these parameters feedback to affect climate change. Other important areas of research include the effects of land-use change on ecosystems, interactions between land use and aquatic systems, pollutant cycling and human health, nitrogen flows, and groundwater dynamics, and how both climate and land-use change affect ecosystem services. To better assess these effects, the blue ribbon panels have recommended developing new networks to monitor water, land-use change, and plant and animal communities, making better use of current technology such as remote sensing, and developing new monitoring techniques.

The previous and current research direction at the MEF meshes well with research priorities identified by national and global scale assessments. Watershed hydrologic studies and greenhouse gas research at the MEF have contributed to our understanding land–surface interactions that affect global climate forcing. Northern peatlands have been identified as at risk due to climate change (Lenton et al. 2008). Research at the MEF will continue to assess the sensitivity and vulnerability of peatlands to climate change. Studies at the MEF and nearby systems also are measuring the trade-offs of managing forests for fiber production versus maximum ecosystem carbon sequestration. This research can be expanded across broader spatial scales and include additional species.

Understanding ecosystem responses to change at multiple scales encompasses a number of recommendations by the blue ribbon panels. Researchers at MEF are assessing carbon pools and fluxes at multiple scales and new studies will refine these assessments and extend to other chemical constituents such as DOM and mercury. We recently used LiDAR to map the vegetation and topography of the South Unit of the MEF. The accuracy and precision of the elevation data provided by LiDAR will increase our understanding of hydrological and chemical flow pathways and allow us to investigate the topographical controls and hotspots of biogeochemical cycling in peatland landscapes (Mitchell et al. 2008c). LiDAR canopy data will provide a new context for measuring vegetation and carbon pools on the MEF.

The gaged watersheds at the MEF have provided valuable insight into the effects of harvesting on water quality and quantity. We plan to extend our data and use MEF flow and chemistry data within the context of the larger Great Lakes region to determine the effects of land-use change on water resources. Although our two control watersheds (S2 and S5) have been used for comparisons of our manipulations at MEF, they have seldom been compared with other watersheds in the region. We plan to expand our small watershed research to determine the cumulative effects of forest management and natural disturbances on water yield and chemistry in larger landscapes. The scaling up of our watershed, carbon and mercury research will likely lead to developing collaborations with a new set of scientists proficient at using tools like remote sensing to help in the scaling process.

The mercury research program has contributed to our understanding of mercury cycles in northern forest landscapes, but much work remains. Although we have begun to tease apart the chemical and topographic controls on the mercury methylation process, we need to more fully understand how the sources of sulfate and DOM affect the methylation process and whether certain fractions of DOM are more important to methylation than others. There has been little research on the effects of climate change on mercury cycling. Climate change likely will affect hydrology, composition and productivity of plant communities, decomposition rates, and atmospheric inputs of mercury and other constituents. As a result, mercury currently stored in terrestrial systems may become more or less available for remobilization depending on changes in these processes. Investigating mercury speciation under elevated temperature, CO_2, and variable water tables could enhance our ability to predict the effect of climate change on mercury cycling.

The location of the MEF within the northern forest provides unique research opportunities related to the response of forests to climate change. For example, its location near the edge of the boreal forest places the MEF near the southern boundary of the range of many important plant species, notably black spruce. As a result, the MEF would be ideal for monitoring the long-term impacts of climate change on lowland conifer ecosystems. A comprehensive monitoring program targeted at capturing vegetation responses to climate change would strengthen the research portfolio at the MEF since many of our long-term measurements are currently focused on water or carbon cycling. A planned, large-chamber experiment will measure ecosystem responses to soil and air warming up to 9°C and doubled CO_2 concentrations in the black spruce bog in the S1 watershed. This experiment should reveal thresholds of change for peatland ecosystems under warming or elevated CO_2 or under the combined effects of both elevated temperature and CO_2.

As discussed earlier, the MEF is part of multiple networks, both national and international, which contribute to understanding ecosystems at larger scales when combined with other sites. Data collected at the MEF NADP and MDN sites and the entire network have advanced research in atmospheric and ecosystems science. One new network of sites is assessing the inputs of mercury in litterfall across the eastern United States. The MEF is now in its second year contributing to this effort. Although not currently part of the AmeriFlux Network, in the next few years we plan to add the eddy covariance data from the Bog Lake fen to the AmeriFlux Network of sites. As new networks develop, it is a priority for the MEF to contribute relevant information and expertise.

In our vision, the MEF will continue to contribute to priority basic and applied research through studies initiated by our scientists, university and other agency collaborators, graduate students, and postdoctoral scholars. The MEF has been and continues to be a test site for new monitoring technologies. A core activity is the extension of our long-term hydrological, meteorological, biogeochemical, and trace gas flux data series. In addition to continued monitoring that will extend our long-term records on forest harvest effects, we will conduct manipulative experiments aimed at issues that are important today and that likely will be important in the future (e.g., climate change and carbon). Based on our extensive long-term databases and rich history of research, we are well poised to address these important future issues.

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