

**RESEARCH AND OBSERVATORY CATCHMENTS: THE
LEGACY AND THE FUTURE**

Hydrological and meteorological data from research catchments at the Marcell Experimental Forest, Minnesota, USA

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Abstract

The Marcell Experimental Forest (MEF) in northern Minnesota, USA, with hydrological research and monitoring of peatland catchments in a low-topographic relief landscape, contrasts with the mountainous terrain that typifies most research catchments. Six research catchments were instrumented and hydrological and meteorological monitoring was initiated during 1960. Paired-catchment studies, which started during 1969, have been used to assess land management and environmental change effects on forests, water availability, and biogeochemistry. Over the decades, the research and collaborations have proliferated to include new monitoring and ecosystem experiments. We provide an overview of available datasets and access information for hydrological and meteorological data. Data on streamflow, water table elevation, precipitation, snow, ground frost, air temperature, soil moisture, upland runoff, and water chemistry are discoverable with associated metadata and are archived through several Web-based, community repositories. The research programme is ongoing and we anticipate updates on an annual or more frequent basis. Additionally, we aim to release other physical, chemical, and isotopic measurements associated with long-term catchment monitoring and studies at the MEF.

KEYWORDS

bog hydrology, monitoring, northern peatlands, streamflow, upland forest, upland-peatland catchments, water table elevation

1 | DATASET NAME

Long-term monitoring data from the Marcell Experimental Forest.

2 | SITE, RESEARCH PROGRAMME, AND DATA APPLICATIONS

The Marcell Experimental Forest (MEF) in northern Minnesota, USA, may be the longest, uninterrupted monitoring programme on peatland

hydrology. When established during the 1960s, the MEF expanded the research scope of the USDA Forest Service catchment studies (Verry, Bay, & Boelter, 2011). The geographic setting is a post-glacial landscape having deep (~50 m) outwash sands. There is less than 12 m of topographic relief within any of six research catchments and each catchment has a central peatland (12–33% of the area). These characteristics were distinct from the mountainous catchments that typified other Forest Service catchments at the time (Verry, Bay, & Boelter, 2011). In contrast to some other well-known ecosystem studies with peatlands (Hribljan, Kane, Pypker, & Chimner, 2014; Marttila & Kløve, 2010; Talbot, Roulet, Sonnentag, & Moore, 2014; Wallin et al., 2015), the MEF peatlands have no history of anthropogenic

Richard L. Kyllander and Elon Sandy Verry are retired.

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MARCELL EXPERIMENTAL FOREST MINNESOTA, USA

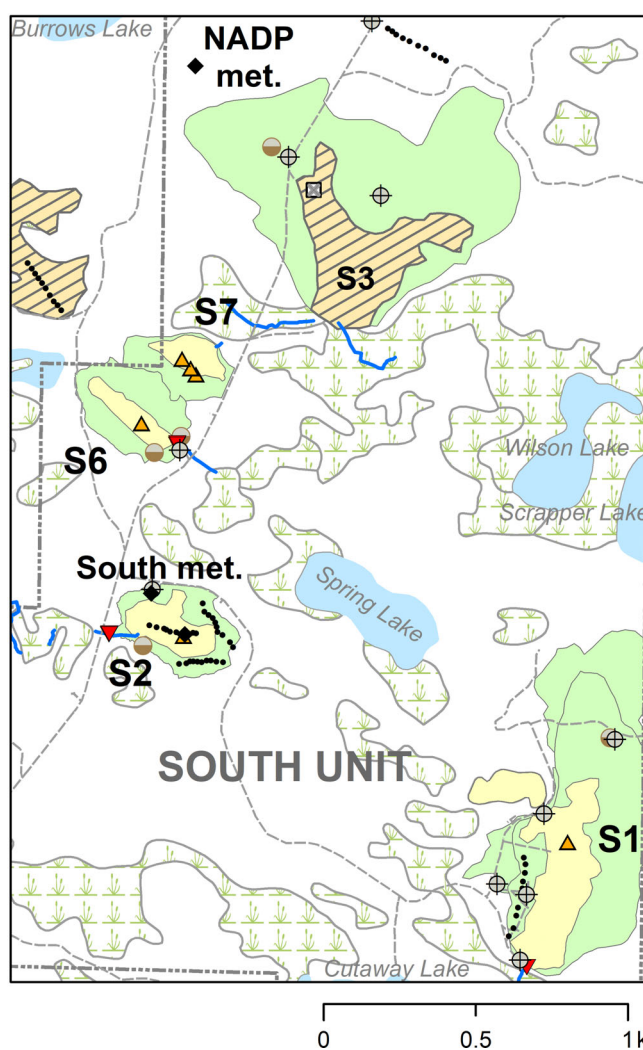
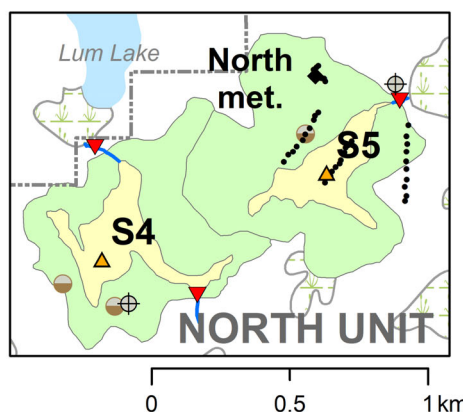
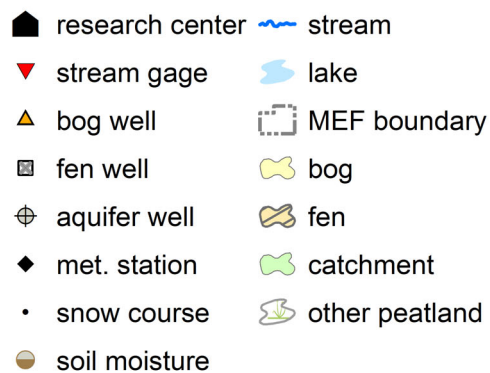
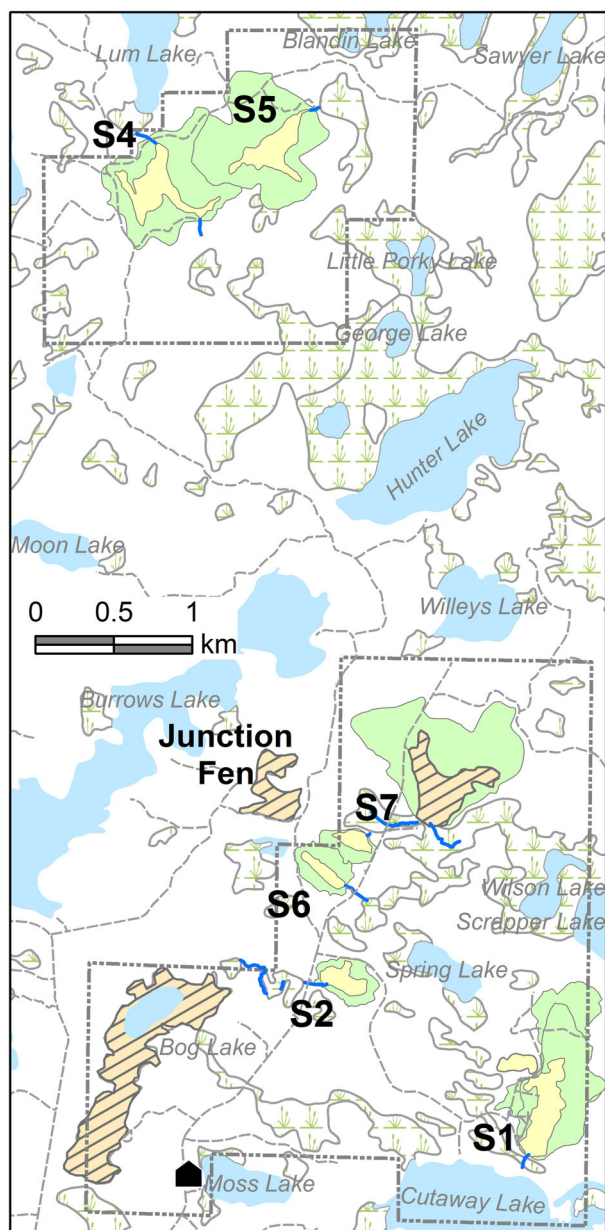


FIGURE 1 Legend on next page.

drainage (except drainage experiments) or hydrologic effects of earthen levees (Holden, Chapman, & Labadz, 2004; Minkinen, Byrne, & Trettin, 2008). Even today, few catchment studies focus on the climate, ecosystem types, vegetation communities, drainage history, and geological setting that characterize the MEF (Verry, 2003) despite the widespread presence of subdued topography and boreal peatlands around the Northern Hemisphere (Wieder & Vitt, 2006). Accordingly, the research programme fills an important role in environmental monitoring and research (Kolka, Sebestyen, Verry, & Brooks, 2011), recognition of the importance of peatlands in catchment studies (Bay, 1968; Urban, Verry, Eisenreich, Grigal, & Sebestyen, 2011; Verry, Brooks, Nichols, Ferris, & Sebestyen, 2011), establishment of forest management guidelines (Verry, 2004), and the development of peatland representation in hydrological, biogeochemical, and Earth Systems Models (Brooks et al., 2011; Cui, Li, & Trettin, 2005; Jiang et al., 2018; Ma et al., 2017; Ricciuto et al., in press; Shi et al., 2015).

The climate is continental with warm summers and cold winters (Koppen classification Dfb; Peel, Finlayson, & McMahon, 2007). From 1961 to 2019, the mean annual air temperature was 3.5°C, with absolute minimum and maximum daily values ranging from −46°C to +38°C. Mean annual precipitation was 787 mm (414–1105 mm). Snow is usually present from November to March or April.

Six zero-order research catchments are clustered in two areas that are about 5 km apart (Figure 1). Monitoring started as early as 1960, depending on when any particular catchment was instrumented (Sebestyen et al., 2011; Table 1). The catchments are designated as S1, S2, S3, S4, S5, S6, or S7, with the S abbreviating swamp (peatlands were rarely identified by type or function when named). The S1, S2, S3, S6, and S7 catchments are on the South Unit. The S4 and S5 catchments are on the North Unit. All catchments drain via the Mississippi River to the Gulf of Mexico. The S4 catchment is atypical because it spans a continental divide and drains via outlet streams to both the Hudson Bay (north outlet, gauge S4N) and the Gulf of Mexico (south outlet, gauge S4S).

An outwash sand covers about 1/3 of the 1140 ha MEF and the rest is covered with glacial till (Paulson, 1968). The upland mineral soils are Entisols or Alfisols (Nyberg, 1987). Each catchment, except S3, has a raised-dome black spruce (*Picea mariana*) – tamarack (*Larix laricina*) – *Sphagnum* bog. The S3 catchment has a tamarack – shrub fen (S3; Sebestyen, Dorrance, et al., 2011). Raised-dome bogs (ombrotrophic peatlands) formed in till-lined ice-block depressions (Verry, Bay, & Boelter, 2011). Fens occur where groundwater exchanges between the outwash aquifer and peat. The organic soils (Histosols) in either peatland type are several m to nearly 10 m deep (Hill et al., 2016; Parsekian et al., 2012; Verry & Janssens, 2011).

Forest overstory and understory species have been surveyed throughout each catchment (summarized by Perala & Verry, 2011; Sebestyen, Verry, & Brooks, 2011; a 1968 survey is published, Verry, 2018). Upland forest cover is mainly aspen (*Populus tremuloides*, *P. balsamea*, or *P. grandidentata*) – birch (*Betula papyrifera*) or conifer (*Pinus strobus*, *P. resinosa*, *P. banksiana*, *Picea glauca*, *Abies balsamea*) with other northern hardwood species (e.g., *Acer rubrum*, *A. saccharum*, *Quercus rubra*).

Research and collaborations have proliferated over the decades to include new monitoring and ecosystem manipulations, notably, a recent, ongoing, large-scale climate manipulation study (the SPRUCE Experiment, see Supplements; Hanson et al., 2017; <https://mnspruce.ornl.gov>). Paired-catchment studies have been used to assess land management and environmental change effects on forests, water availability, and biogeochemical cycles (Table 1; Kolka et al., 2011; Sebestyen & Verry, 2011; Sebestyen, Verry, & Brooks, 2011). All experiments have involved partial catchment areas, either a peatland or the surrounding upland forest. Two catchments (S2 and S5) are maintained as references.

Ongoing monitoring outside of catchment studies includes: net carbon dioxide and methane exchange at a poor fen (<https://ameriflux.lbl.gov/sites/siteinfo/US-MBP>), atmospheric deposition (National Atmospheric Deposition Program National Trends Network and Mercury Deposition Networks site MN16; <http://nadp.slh.wisc.edu/>), upland soil temperature (Sebestyen et al., 2020), snow depth and water equivalents (Sebestyen et al., 2020a), a long-term soil productivity site (Powers et al., 2014), and wood decomposition.

3 | MONITORING AND LONG-TERM RECORDS

Although now being transitioned to electronic sensors and datalogging, the originally-installed, mechanical stripchart recorders still record air temperature, streamflow, and water table levels. Float-tape-counterweight systems have been used for water level monitoring and water monitoring infrastructure has been heated for winter-time operation. All instruments have been checked weekly or more often. Missing values were estimated from parallel measurements in other catchments/sites. The reported periods of monitoring by catchment or site are depicted in Figure 2.

Daily minimum and maximum air temperature is reported for two upland locations (South and North) and one bog location (S2 Bog; Sebestyen et al., 2020d). Each site has a Belfort Instruments (Baltimore, MD) model FW-1 hygrothermograph (0.6°C resolution) and US Weather Bureau style maximum and minimum thermometers in a Standard National Weather Service Shelter (NWS, 2014). Thermometers are read weekly and reset during site visits. Weekly maximum and

FIGURE 1 Map of the Marcell Experimental Forest and catchments. The detailed maps of the north and south units show infrastructure that is associated with datasets that are described in this data note. Catchments S1–S6 are highly instrumented for ongoing, long-term monitoring and research. Catchment S7 has little infrastructure and has been used for studies lasting only several years

TABLE 1 Geographic information, elevation ranges, and experiments listed by research catchment

Catchment	Total area (ha)	Peatland type and area (ha)	Elevation range (m)	Outlet latitude and longitude (decimal degrees)	Catchment experimentation
S1	33.2	Bog, 8.1	412–430	93.472 W, 47.504 N	Successive stripcuts (1969, 1974) and SPRUCE warming/enhanced atmospheric carbon dioxide in the peatland (2014–ongoing; Hanson et al., 2017)
S2	9.7	Bog, 3.2	420–430	93.473 W, 47.514 N	None (Sebestyen, Dorrance, et al., 2011)
S3	72.0	Fen, 18.6	412–429	93.468 W, 47.522 N	Fen clearcut (1972–1973)
S4	34.0	Bog, 8.1	428–438	93.487 W, 47.558 N (S4N); 83.472 W, 47.558 N (S4S)	Uplands clearcut (1970–1972) and fertilized (1978)
S5	52.6	Bog, 6.1	422–438	93.473 W, 47.564 N	None (Sebestyen, Dorrance, et al., 2011)
S6	8.9	Bog, 2.0	423–435	93.470 W, 47.520 N	Uplands deciduous cover clearcut (1980), then converted to conifer cover (1983); Peatland received enhanced sulphate deposition (2001–2008; Coleman Wasik et al., 2015; Jeremiason et al., 2006)
S7	7.0	Bog, 2.1	416–435	93.468 W, 47.522 N	Bog drainage, 1967–ongoing (Boelter, 1972), monitoring ended 1970; Upland hillslope harvest study, 2010–2013 (2012; McCarter et al., 2021; McCarter, Sebestyen, Eggert, Kolka, & Mitchell, 2020)

Note: All harvest studies are described in Sebestyen, Dorrance, et al. (2011), Sebestyen and Verry (2011) and Sebestyen, Verry, and Brooks (2011).

minimum thermometer values were used to calibrate the recorded temperatures and to prorate values from stripcharts if different.

Precipitation amount has been measured in forest clearings at three sites (S2 = South, S5 = North, and NADP) and daily values are reported (Sebestyen et al., 2020f). Belfort Universal Recording Precipitation Gauges (chart recorders) were used prior to replacement with digital NOAA IV total precipitation gauges (ETI Instrument Systems, Ft. Collins, CO) during 2010 (NADP and South) or 2014 (S5). Each recording gauge has a paired Standard Rain Gauge (SRG; NWS, 2014) for verification of total weekly precipitation. When freezing was not expected, gauges had funnels installed to collect rainfall. During winter, antifreeze and oil were added to receiving buckets to melt snow and limit evaporation. Daily values were read from stripcharts and prorated to the weekly total (SRG) when a stripchart and the adjacent SRG were not equal. The digital gauges record increments of precipitation every 15 min, the data are summed daily, and these values are backwards compatible with the Belfort gauges.

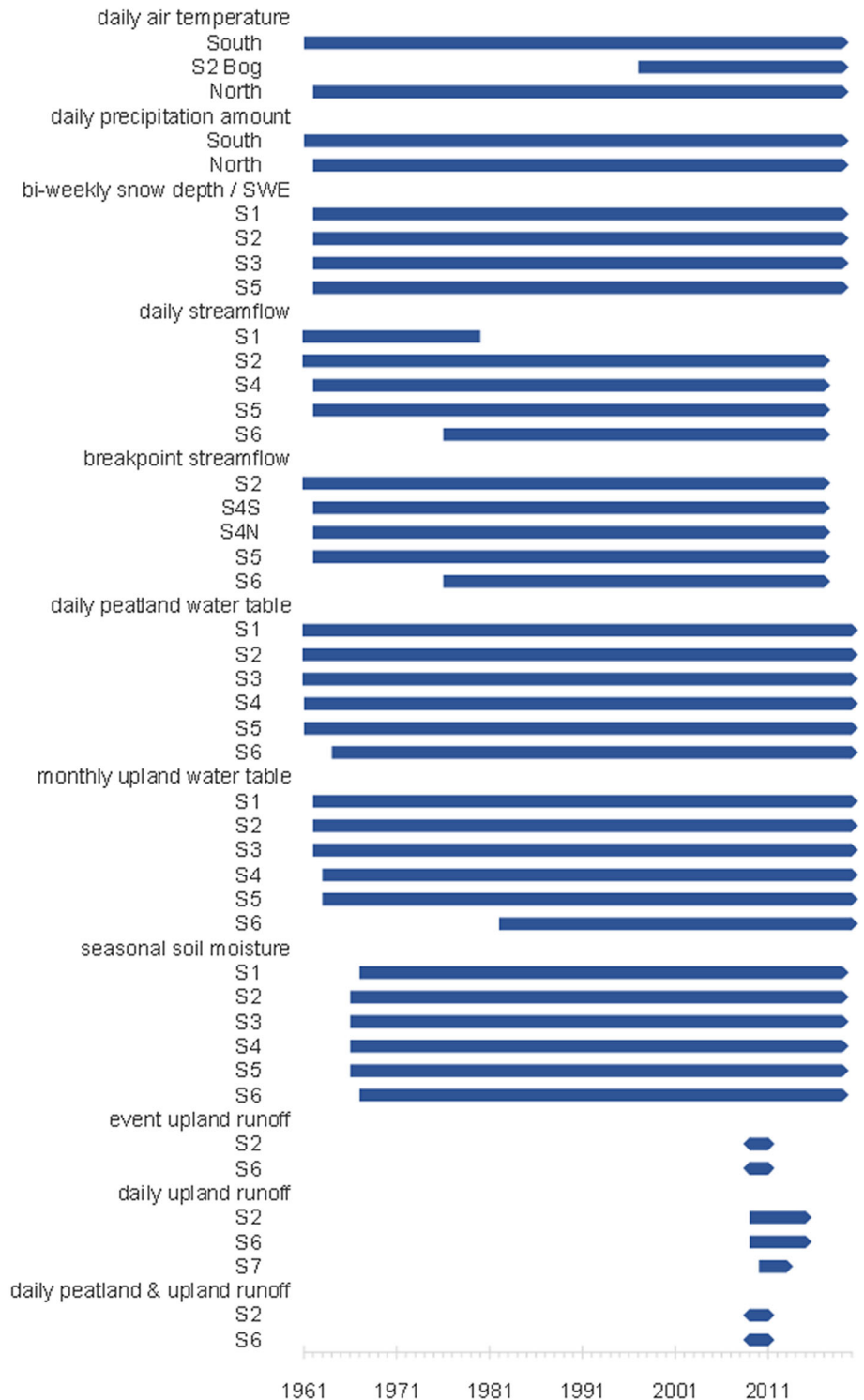
Snow water equivalents (SWE), snow depth, and ground frost depth have been reported for seasonal or biweekly measurements from 10 permanent snowcourses under various forest cover types and at the North meteorological station (Sebestyen et al., 2020c; Sebestyen, Verry, et al., 2020a). Each snowcourse has 10 sample points. Measurements in any year started in February at the typical time of maximum snow depth and were repeated every 2 weeks until no snow remained. Depth was read along a Mount Rose (Federal) Snow Tube (2.5 cm resolution). The mass difference between an empty and full snow tube was converted into water equivalents (28 g snow = 2.5 cm water; 0.25 cm resolution). Frost depth was measured with a Lake States frost penetrometer (Stoeckeler & Thames, 1958)

from 1962 to 2011. Frost depth was estimated to the nearest 2.5 cm, with a maximum possible reading of 45 cm (>45 cm was recorded as 45 cm). Starting during 2012, frost depth was measured using a 1.0 cm or 1.3 cm masonry bit with a 91.4 cm shank and a portable drill. Frost depth was estimated as the distance until resistance to drilling decreased in underlying unfrozen ground (2.5 cm resolution).

Daily streamflow data are available for all but the S3 and S7 catchments (Verry, Elling, Sebestyen, Kolka, & Kyllander, 2018a). Stream stage was recorded from 1961 to 1981 using a Belfort FW-1 recorder (0.6-cm precision) at a type-H flume at S1. At the S2, S4S, S4N S5, and S6, stage is currently measured in stilling wells behind 120° V-notch weirs. All but S2 were at some period configured as flumes with type-H facings. Stage is recorded at S2 using a Stevens Water Monitoring Systems (Portland, OR) Type A-35 recorder with 0.3 cm precision or FW-1 recorders at S4S, S4N, S5, and S6. Stripcharts were compared to point measurements (0.03 cm precision; Brakensiek et al., 1979) to further improve the accuracy of stage values. Streamflow was calculated using stage-discharge relationships (Gwinn & Parsons, 1976; Hertzler, 1938). Sub-daily, non-fixed interval stage and streamflow data are available for the S2, S4S, S4N, S5, and S6 catchments (Sebestyen et al., 2020b) as breakpoint values (Copley, 1942; Johnson & Dils, 1956). Sub-daily streamflow was totalled for each day and streamflow from the S4S and S4N gauges were summed to calculate total streamflow for the S4 catchment (Verry et al., 2018a).

Depth to water table has been measured near the centre of each peatland and daily maximum water table elevation is reported (Sebestyen, Burdick, et al., 2021). Water levels in open pools have been measured with FW-1 stripchart recorders and verified with

FIGURE 2 Timelines of measurements by type and location. Forward arrows indicate ongoing monitoring/measurement and these are the datasets that we intend to update annually or more frequently. Backward arrows indicate previous monitoring/measurements that will be included when possible. We do not include timelines for water chemistry or isotopic datasets that are mentioned in the narrative



weekly manual measurements. Instrument shelters serve as elevation datums (water table elevation = shelter elevation – depth to water). To prevent freezing, shelter heaters were added between 1990 and 2005. Before heating, water levels were manually measured in adjacent wells or extrapolated from water-table recession curves for frozen periods.

Depths to water tables in the uplands have been measured each month at 12 wells, with one or more per catchment. Monthly water table

elevation is reported (Sebestyen, Verry, et al., 2021). Each upland well is screened belowground and penetrates through the glacial till layer (if present) into the outwash sand aquifer (Verry & Janssens, 2011). Depths were manually measured using a chalked tape before 2005 and a portable electronic water level sensor (0.3 -cm precision) thereafter. Elevation was calculated by subtracting the depth to water from the top elevation of a well. Depth to water in one well (the 305 well in the S3 catchment) has been recorded using a Stevens Type-F recorder (0.3 -cm

resolution) and daily maximum water table elevation is reported (Verry, Elling, Sebestyen, Kolka, & Kyllander, 2018b).

Upland soil water content has been measured at 10 sites using the neutron probe technique, with seasonal values reported as cm of available water along aluminium access tubes (3.8-cm diameter, up to 3 m belowground; Dymond et al., 2020). Soil textures range from sand at the surface to clay (deeper, where present). A Troxler (Research Triangle Park, NC) Model 105 Depth Moisture Gauge was used before 1990 and Series 4300 Gauge thereafter. Volumetric soil moisture (0.24% precision) was read (60 s) over successive 0.3 m depth increments taken in May (deciduous leaf emergence), late September (leaf senescence and abscission), and early November (before soil freezing). Data were converted to available soil water (cm) by multiplying % soil moisture by the length of the depth interval (0–46 cm, 0–76 cm, 0–137 cm, and 0–229 cm) and then subtracting the 15-bar wilting point constant of the dominant overstory specie.

Upland runoff as overland flow (OF) and lateral subsurface stormflow (SSF) have been measured on an event basis at north- and south-facing hillslopes in the S2 and S6 catchments. OF occurs as runoff through the forest floor, predominantly when mineral soil is frozen, and SSF occurs when saturation develops above a confining clay horizon (Verry, Brooks, et al., 2011). A metal pan is used to route OF into a collection system (5-L pail that overflows to a 700-L tank) and a well screen in a trench captures SSF separately from OF. Tank volumes were read from calibrated stand pipes (5-L resolution) after each rainfall or snowmelt event. Water levels are also recorded every 5 min in OF and SSF tanks (0.3-cm resolution). Water levels are converted into volumes using a height-volume relationship and daily estimates are summed from sub-daily values. We report event and daily runoff from 2009 to 2015 (Sebestyen & Kyllander, 2018). We combine these logged runoff data with hydrograph separation to apportion daily amounts of streamflow that originated from the peatland and uplands of both the S2 and S6 catchments (available through Sebestyen & Kyllander, 2017). We determine recession equations (Langbein, 1938) when both peatland and upland runoff occurred, and when only peatland runoff occurred. With the equations, we calculated daily amounts of streamflow that originated from the S2 and S6 peatlands. We subtracted the peatland runoff values from streamflow to estimate daily upland runoff. Similar runoff collectors were operated in the S7 catchment from 2010 to 2013 (McCarter et al., 2020).

Water chemistry of stream, snowpack, upland runoff, peatland porewater, upland soil water, and groundwater has been measured since the 1960s, with some data published (Griffiths & Sebestyen, 2016a, 2016b; McCarter et al., 2021; Pierce et al., 2019a, 2019b; Sebestyen et al., 2019; Sebestyen, Lany, Aspelin, et al., 2021; Sebestyen, Lany, Larson, et al., 2021; Sebestyen, Funke, Cotner, Larson, & Aspelin, 2020; Sebestyen, Lany, Aspelin, Oleheiser, & Larson, 2021a, 2021b) and much more to come. Associated water isotope data are presented in an accompanying Data Note (Stelling, Sebestyen, Griffiths, Mitchell, & Green, in press). Precipitation chemistry has also been collected at the S1 and S2 catchments on an event-basis (Sebestyen et al., 2020) and used to calculate daily bulk

atmospheric deposition (Sebestyen, 2020). See a description of water sampling, processing, and analytics in Supplement 2.

4 | DATASET CONTRIBUTORS

Stephen Sebestyen and Randall Kolka (administrative lead) lead research planning at the MEF. Sandy Verry is the former project lead. Nina Lany coordinates data compilation/archiving. Richard Kyllander, Tyler Roman, and Jacob Burdick have been critically involved with site management, maintenance, and data collection. Others have played prominent roles: Roger Bay, Don Boelter, Carrie Dorrance, Art Elling, Clarence Hawkinson, Doris Nelson, Donna Olson, Dwight Streblow, and Eric Troumbly (USDA Forest Service), and Katy Johnson and Anne Gapinski (University of Minnesota). Others have briefly helped and some regrettably are no longer known to us despite contributions to monitoring and site operation.

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The Northern Research Station of the USDA Forest Service funds the MEF, the authors, and field technicians, past and present. The data are owned by the US Government and can be used without additional permissions or fees. When used in a publication, presentation, or other research product, please cite appropriately.

DATA AVAILABILITY STATEMENT

We have cited 28 individual datasets in this Data Note. Each described dataset is freely available and directly accessible via a digital object identifier (DOI), each of which can be found in the reference list. Here, we provide a general explanation of the data publications. Most long-term, ongoing datasets are posted at the Environmental Data Initiative (EDI; <https://environmentaldatainitiative.org/edi/>) with code (MatLab, Python, R, SAS, SPSS, and tidyR) to access and download data packages. Data will receive new DOIs when updated; preceding versions will be maintained and link to the most recent version. Some data are posted at the Forest Service Research Data Archive (<https://www.fs.usda.gov/rds/archive/>). Data related to the SPRUCE experiment are hosted on the Terrestrial Ecosystem Science Focus Area of Oak Ridge National Laboratory data portal (<https://mnspruce.ornl.gov/public-data-download>). Downloadable files include XML or PDF metadata and CSV data tables. Monitoring continues and updates will be forthcoming as stripcharts are digitized or data otherwise acquired. Many other legacy and new sensing/logging system data sets will be prepared as time and resources allow. Direct inquiries about data and research collaborations to the lead author (stephen.sebestyen@usda.gov) or Randy Kolka (randall.k.kolka@usda.gov).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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