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RESEARCH AND OBSERVATORY CATCHMENTS: THE LEGACY AND THE FUTURE

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# Long-term hydrology and aquatic biogeochemistry data from H. J. Andrews Experimental Forest, Cascade Mountains, Oregon

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## Abstract

The H. J. Andrews Experimental Forest (HJA) encompasses the 6400 ha Lookout Creek watershed in western Oregon, USA. Hydrologic, chemistry and precipitation data have been collected, curated, and archived for up to 70 years. The HJA was established in 1948 to study the effects of harvest of old-growth conifer forest and logging-road construction on water quality, quantity and vegetation succession. Over time, research questions have expanded to include terrestrial and aquatic species, communities and ecosystem dynamics. There are nine small experimental watersheds and 10 gaging stations in the HJA, including both reference and experimentally treated watersheds. Gaged watershed areas range from 8.5 to 6242 ha. All gaging stations record stage height, water conductivity, water temperature and above-stream air temperature. At nine of the gage sites, flow-proportional water samples are collected and composited over 3-week intervals for chemical analysis. Analysis of stream and precipitation chemistry began in 1968. Analytes include dissolved and particulate species of nitrogen and phosphorus, dissolved organic carbon, pH, specific conductance, suspended sediment, alkalinity, and major cations and anions. Supporting climate measurements began in the 1950s in association with the first small watershed experiments. Over time, and following the initiation of the Long Term Ecological Research (LTER) grant in 1980, infrastructure expanded to include a set of benchmark and secondary meteorological stations located in clearings spanning the elevation range within the Lookout Creek watershed, as well as a large number of forest understory temperature stations. Extensive metadata on sensor configurations, changes in methods over time, sensor accuracy and precision, and data quality control flags are associated with the HJA data.

KEYWORDS

long-term data, precipitation chemistry, research catchments, small watersheds, stream chemistry, stream discharge

## 1 | DATASET NAME

Long-term hydrology and aquatic chemistry data from the H. J. Andrews Experimental Forest.

## 2 | INTRODUCTION AND FINDINGS FROM PRIOR RESEARCH

The H. J. Andrews Experimental Forest was established in 1948 to study watershed-scale processes and responses to forest management. Today, there are nine gaged watersheds on HJA (Figures 1 and 2), plus a USGS gaging station on Lookout Creek. Measurements of precipitation and air temperature began in 1958 near the streamflow gage at WS 2 (CS2MET), in association with the first small watershed experiments (Table 1). The numbers of sites and parameters measured have expanded over time and now include benchmark and secondary meteorological stations (Table 2) located in clearings spanning the elevation range within Lookout Creek watershed (Daly et al., 2019).

Initial experimental treatments in the small watersheds focused on forest harvest, contrasting clearcutting, patch cutting and shelterwood cuts. Numerous studies of these treatments have continued over time and many additional research projects have used these data to evaluate basic processes. Here we provide a brief overview of the research and acknowledge that it is not inclusive of the large number of papers that have been published using these data. A full list of research publications from HJA are available online: https://andrewsforest.oregonstate.edu/publications.

Seventy years of hydrology research at HJA has provided insights into interactions among hydrology, land use, climate and forest dynamics. Long-term paired-watershed experiments have revealed that harvest of old-growth forest and conversion to young plantations initially results in increased peak flows and annual discharge (Harr, 1983; Harr & McCorison, 1979; Jones & Grant, 1996; Rothacher, 1970) although at some watersheds, responses were lagged or minimal (Harr et al., 1982; Harr & McCorison, 1979). Perry and Jones (2017) observed that decades after harvest, late summer stream discharge decreased in the watersheds with young forests. Harr (1986), Berris and Harr (1987) and Harr and Coffin (1992)

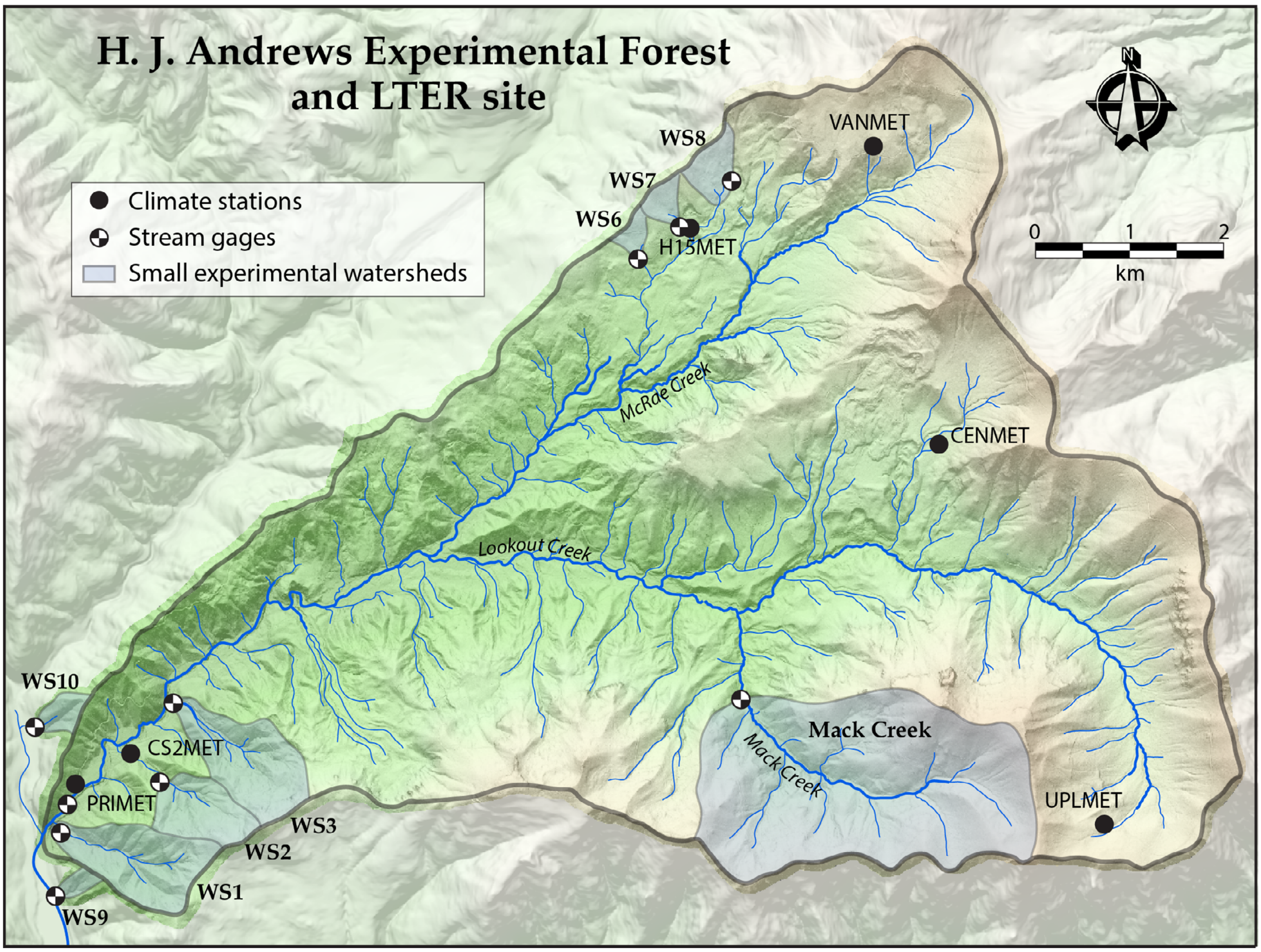


FIGURE 1 Map of H. J. Andrews Experimental Forest, Blue River, Oregon, showing experimental watersheds, stream gage locations and weather stations

**FIGURE 2** (a) Photo of Lookout Creek near the USGS gaging station. (b) Photo of headwater stream under dense vegetation. S. L. Johnson, photographer

evaluated forest management effects on snowpack accumulation and Harr (1981) and Perkins and Jones (2008) documented rain-on-snow contributions to major floods. Studies of forest-water relationships continue (Brooks et al., 2010; Johnson et al., 2000; Moore et al., 2004; Perry & Jones, 2017; Running et al., 1975). Multiple models using these hydrologic data have been used to explore watershed dynamics (Abdelnour et al., 2011; Dong et al., 2019; Garcia, 2014; McGuire et al., 2007; Tague & Band, 2001; Ward et al., 2018).

The HJA has been a focal location for the study of hyporheic zones in mountain stream networks (Gooseff et al., 2006; Kasahara & Wondzell, 2003; Ward et al., 2016; Wondzell, 2011; Wondzell & Swanson, 1996a) with important implications for stream temperature, conductivity, streamflow, nutrient cycling and carbon dynamics (Corson-Rikert et al., 2016; Johnson, 2004; Wondzell, 2011). The HJA has also been a focal location for numerous studies of hydrologic flow paths and water residence times, many using isotopic tracers (Cain et al., 2019; McGuire et al., 2005; Mosquera et al., 2018; Rodriguez et al., 2018; Ward et al., 2017).

Water chemistry research in the small watersheds, initiated during the International Biological Program (IBP), focused on nutrient budgets (Sollins et al., 1980; Triska et al., 1984) and multiple solutes

**TABLE 1** Characteristics of stream gage watersheds, average age of dominant overstory vegetation, and timing of start of gaging and stream chemistry analyses

| Watershed | Gaged area (ha) | Gage Elev. (m) | Max Elev. (m) | Age of forest (year) | Management history | Stream gage start | Stream chemistry start |
|---|---|---|---|---|---|---|---|
| 1 | 96 | 439 | 1027 | 50 | 100% Clearcut 1962–1966; burned 1967; no roads | 1952 | 2003 |
| 2 | 60 | 545 | 1079 | 500 | Reference, no harvest | 1952 | 1981 |
| 3 | 101 | 476 | 1080 | Mixed | 25% Patch clearcut 1963; 6% roads 1959 | 1952 | – |
| 6 | 13.0 | 878 | 1029 | 45 | 100% clearcut 1974; 9% roads | 1963 | 1971–1987; Restart 2002 |
| 7 | 15.4 | 918 | 1102 | mixed | 60% Overstory harvest 1974; remaining 40% removed 1984; 12% non-commercial thin 2001 | 1963–1987; Restart 1995 | 1971–1987; Restart 2002 |
| 8 | 21.4 | 962 | 1182 | 170 | Reference, no harvest | 1963 | 1971 |
| 9 | 8.5 | 426 | 731 | 500 | Reference, no harvest | 1968 | 1968 |
| 10 | 10.2 | 461 | 679 | 44 | 100% Clearcut 1975 | 1968 | 1968 |
| Mack | 580 | 755 | 1626 | 500 | 13% Harvest and road on ridgeline 1962 | 1979 | 1980 |
| Lookout | 6242 | 422 | 1627 | mixed | 25% Harvest 1952–1985; 10% roads | 1949 | 2005 |

*Note:* For more details https://andrewsforest.oregonstate.edu/research/infrastructure/watersheds.

(Martin & Harr, 1988). These early studies documented very low concentrations of nitrogen in streams and precipitation and high concentrations of phosphorus, likely related to historic volcanic deposition. Watershed harvest and burning of logging debris resulted in slight increase in nitrate concentrations (Fredriksen, 1975; Martin & Harr, 1989; Sollins et al., 1981) but limited response of other solutes. Continued small watershed research at the HJA has revealed how temperature, precipitation, forest disturbance and succession influence carbon and nutrient dynamics (Lajtha & Jones, 2018; Safeeq et al., 2020) and projected potential implications of climate change on biogeochemical processes in forested watersheds (Dong et al., 2019). Dissolved organic nitrogen (DON) is the dominant form of nitrogen in streams (Fredriksen, 1975; Martin & Harr, 1988; Vanderbilt et al., 2003). Experimental additions of $^{15}N$ demonstrated rapid uptake and transformation of ammonia and export of nitrate, but limited instream denitrification (Ashkenas et al., 2004; Sobota et al., 2012). Although Pacific Northwest forests produce and sequester large amounts of carbon, concentrations of dissolved organic carbon (DOC) in streams are low (Argerich et al., 2016). DON and DOC fluxes increased with seasonal and storm precipitation (Hood et al., 2006; Lee & Lajtha, 2016; van Verseveld et al., 2008; Wondzell & Swanson, 1996b). Evaluation of nitrogen concentrations and discharge over time in reference watersheds has shown decreasing trends at some watersheds for some periods, but presence of significant trends varies with the time period examined (Argerich et al., 2013).

These ongoing, long-term hydrologic and biogeochemical data from treated and reference forested watersheds are the product of several generations of dedicated researchers. These data become more valuable with time and will continue to provide an important foundation for examining hydrologic and biogeochemical dynamics, such as those resulting from shifts in natural disturbance regimes, climate change, anthropogenic impacts, and fire.

## 3 | WATERSHED DESCRIPTIONS

The HJA is located within the Willamette National Forest in the central Cascade Mountains of Oregon, USA and comprises the full Lookout Creek basin. Average slope gradients range from 30% to 60% and elevations range from 420 to 1630 m. The geology of the lower elevations of the Lookout Creek watershed (including WS 1, 2, 3, 9, 10) is highly weathered Oligocene tuffs and breccias that are prone to mass wasting. The upper elevation portion of the HJA (above ~800 m, and including WS 6, 7, 8 and Mack Creek) is underlain by Miocene andesitic basalt lava flows (Dyrness, 1967; Swanson & James, 1975; Swanson & Swanston, 1977). Soils are loamy, have very high infiltration capacity, and are well-drained in most locations (Dyrness, 1969; Dyrness & Hawk, 1972; Rothacher et al., 1967).

The climate is Mediterranean, with warm, dry summers and cool, wet winters. Mean daily air temperature is 18°C in July and 2°C in December. Mean annual precipitation ranges from 2200 mm at low elevation to >3000 mm at upper elevation; 75% of precipitation occurs between November and April. The HJA spans the rain-to-snow transition zone; snow rarely persists for more than a few weeks at low elevation, while above 1000 m, seasonal snowpack can persist through the winter or accumulate and melt several times.

The Lookout Creek watershed spans the major mixed conifer forest zones of the Western Cascades range, with the majority of the area within the *Tsuga heterophylla* (western hemlock; below ca. 1000 m) or

*Abies amabilis* (Pacific silver fir; ca. 1000–1550 m) zones. Douglas-fir (*Pseudotsuga menziesii*) is the dominant or co-dominant canopy species over most of the landscape. In the 1950s, the Lookout Creek watershed was dominated by 150–450 year old conifer forests. Logging began in the 1950s and continued through 1980s. Deciduous vegetation is largely restricted to riparian areas and as understory in upland areas.

The gaged small watersheds consist of three sets of small watershed experiments (Table 1): WS 1, 2, 3 (1952–present); WS 6, 7, 8 (1963–present); and WS 9, 10 (1968–present). Each group includes reference (WS 2, WS 8, WS 9) and treated watersheds, including 100% clearcut (WS 1, 6, 10), patch cut (WS 3), and shelterwood harvest (WS 7). All watersheds except WS10 were burned after harvest to remove logging debris.

## 4 | FIELD AND LABORATORY METHODS AND PROCESSING OF DATA

Here we focus briefly on the current methods used in data collection and water sample analyses. Methods have changed over time as new technologies have become available and as measurement standards have changed. Additional methodological details are provided in Supporting Information and as metadata for each database. We suggest that the extensive metadata on sensor configurations, methods changes over time, sensor accuracy and precision, and quality assurance/quality control (QAQC) protocols that are archived with these data should be reviewed before using and analysing these data.

### 4.1 | Stream discharge

Stream gages at the small watersheds and at Mack Creek are trapezoidal flumes and weirs, with stage height measured in adjacent stilling wells. Stage is converted to stream discharge by applying station-specific discharge rating curves (Johnson et al., 2020). Beginning in 1997, metal v-notch weir plates were installed from late June to late September to improve sensitivity of discharge measurements during low flows.

Site specific rating curves have been developed using calibration data collected across a range of flows. Discharge data are now available at 5-min resolution for the entire period of record. Changes in instrumentation and rating curves resulting from small changes in the site characteristics and collection of additional calibration points (summarized in Supporting Information S1) have resulted in updates to the rating curves and discharge data over time. The accuracy of the rating curves varies across discharge levels at each site and ranges from excellent to good. The curves and field discharge data used to construct them are available with the online metadata which allows users of the data to calculate accuracy and uncertainty specifically for the time period of their analysis.

Data quality has been documented for each data point; QAQC protocols include calculation and comparison of magnitude of difference among previous and successive data points, automated comparisons with range of historic data, and evaluation of field notes. For the period of record, the availability of high resolution streamflow data is excellent: 98.8% of hydrology data are high-quality accepted values. Estimated data, which comprise 1.02% of the record, have been calculated for low flow periods when maintenance disrupts the field measurements and flows are stable. Missing data (0.05%) and questionable values (0.03%) are also identified and described. High-frequency, provisional data from each gage are available in near real-time on the HJA webpage (https://andrewsforest.oregonstate.edu/data/streaming), including stage height, stream temperature, air temperature above the stream, and specific conductance.

The Lookout Creek gage is a natural stream cross section and is maintained by the U.S. Geological Survey (USGS 14161500). The U.S. Forest Service Pacific Northwest Research Station operated this gage from 1956 to 1963. The daily record for this period as well as the hourly record of Lookout Creek streamflow from 1950 through 1986 are only available through the HJA webpage.

### 4.2 | Stream water chemistry and precipitation chemistry

Regular stream chemistry sampling and analyses started at the H. J. Andrews Experimental Forest in 1968 in two small watersheds (WS 9, 10). Sampling has since expanded to include additional small watersheds and larger streams (Table 1). Water samples continue to be collected proportionally to streamflow (Fredriksen, 1969), a collection method initiated during International Biological Program to be able to calculate nutrient budgets and fluxes as accurately as possible. Samples are composited at 1-week intervals in the field, and three 1-week samples are composited in the lab before analysis. Data on concentrations and fluxes are provided at three-weekly and monthly intervals (Johnson & Fredriksen, 2019a). QAQC flags for each date identify whether the water sample was complete across the full sampling period (86.0%), or partial (7.0%) as calculated from the sample counter, and therefore not fully representative of the full period. Missing (0.4%), or substitute grab samples (4.6%), manually collected when the streamflow is too shallow for the autosampler or if sampler malfunctioned, are also identified.

Precipitation samples from two rain collectors (Table 2) are analysed for nutrient concentrations. A low elevation rain collector at PRIMET was established in 1968 and an upper elevation rain collector was established in 1972. Several types of precipitation collectors have been used over time (Supporting Information S2). Precipitation totals for each collection period are used to calculate nutrient influxes and are calculated over the same time intervals as stream chemistry (Johnson & Fredriksen, 2019b 2019a). QAQC flags as described above for stream chemistry, are included for precipitation values; the flags identify full (84.9%), partial (14.0%) values.

In 1980, PRIMET became a site for National Atmospheric Deposition Program (NADP-OR10); precipitation samples are shipped weekly to the NADP laboratory. NADP data from PRIMET for ongoing

**TABLE 2** Elevation and timing of start of precipitation, air temperature and other measurements at climate stations

| Site code | Site name | Most relevant to | Elev. (m) | Precip. start | Precip. chemistry | Air temp. start | Wind, radiation start |
|---|---|---|---|---|---|---|---|
| CS2MET | Climatic Station at Watershed 2 | WS 1, 2, 3, Lookout Ck | 482 | 1957 | NA | 1958 | NA |
| PRIMET | Primary Met. Station | WS 1, 2, 3, 9, 10, Lookout Ck | 436 | 1979 | 1968–present | 1972 | 1972 |
| H15MET | High 15 Met. Station | WS 6, 7, 8, Lookout Ck | 909 | 1963 | 1972–present | 1992 | NA |
| GSMACK | Mack Creek Gaging Station | Mack Ck, Lookout Ck | 755 | 1979 | NA | 1987 | NA |
| CENMET | Central Met. Station | Lookout Ck | 1028 | 1995 | NA | 1995 | 1995 |
| UPLMET | Upper Lookout Met. Station | Lookout Ck | 1284 | 1994 | NA | 1994 | 1994 |
| VANMET | Vanilla Leaf Met. Station | Lookout Ck | 1268 | 1987[a] | NA | 1987 | 1987 |
| VARMET | Vanilla Leaf Meadow Met. Station | Lookout Ck | 1300 | 1998 | NA | 2009 | NA |

*Note:* For more details: https://andrewsforest.oregonstate.edu/research/infrastructure/climate.
[a]Site used a prototype of a stand-alone gage until 1998, when VARMET was established as a more reliable precipitation record for this area.

precipitation chemistry and mercury deposition (2002–2011) are available on their webpage (http://nadp.slh.wisc.edu/).

Water chemistry from streams and precipitation is analysed at the Cooperative Chemical Analytical Laboratory (CCAL, Oregon State University, Corvallis, OR). This laboratory specializes in analyses of the low ionic strength samples that occur at HJA. Analyses include suspended sediment, alkalinity, pH, specific conductance, unfiltered total nitrogen and total phosphorus, dissolved organic nitrogen, dissolved organic carbon, and dissolved ammonia, nitrate, and soluble reactive phosphorus. In addition, sodium, potassium, calcium, magnesium, silica, sulphate as sulphur, and chloride are analysed. Initially, aluminium, iron, manganese, and nitrite concentrations were analysed but because they were usually below levels of detection, they were dropped.

Descriptions of the analytical instrumentation, methodology, standard operating procedures, and quality assurance plan, which details internal protocols, are available online: http://www.ccal.oregonstate.edu/. Analytical instruments are calibrated using standard solutions of the analyte of interest. CCAL uses prepared, NIST traceable standard. Calibration correlation should be greater than 0.995. During analyses, drift is monitored with check standards throughout the analysis run. Check standards are from a source or lot other than that of the calibration standards. If drift outside 10% recovery is observed, the run is stopped and the instrument recalibrated, and the analysis is repeated. Sample duplicates are used to calculate precision, with 10% of samples duplicated for every analysis. CCAL participates in multiple national comparisons of quality control including national USGS Standard Reference Water Survey Program to monitor accuracy of analytical procedures. Over the 50 year history of aquatic chemistry analysis by CCAL, only three individuals been responsible for analyses of HJA water. QAQC flags for each analyte by site by date indicate whether the value was acceptable, or below detection limit for that analysis, or questionable (if reporting a high value but not out of historic range), or missing. Some parameters are mathematically derived from other analytical measurements; in those cases, the flags are composites of QAQC flags from each measurement. For the period of record, stream and precipitation chemistry data quality is good: >85% of samples were complete, analytical procedures have been consistent, and replicated lab analyses were in close agreement (Johnson & Fredriksen, 2019a; Johnson & Fredriksen, 2019b).

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## DATA AVAILABILITY STATEMENT

All described datasets are publicly available and released with digital object identifiers (DOI; see References) through the Environmental Data Initiative repository (https://environmentaldatainitiative.org/edi/) or HJA LTER webpage (https://andrewsforest.oregonstate.edu/data). The long-term, on-going hydrology, stream and precipitation chemistry and precipitation datasets discussed in this paper include:

a. Stream discharge in gaged watersheds at the H.J. Andrews Experimental Forest, 1949 to present - database code HF004 (https://doi.org/10.6073/pasta/0066d6b04e736af5f234d95d97ee84f3);
b. Stream chemistry concentrations and fluxes using proportional sampling in the H.J. Andrews Experimental Forest, 1968 to present - database code CF002 (https://doi.org/10.6073/pasta/bb935444378d112d9189556fd22a441d);
c. Precipitation chemistry concentrations and fluxes, H.J. Andrews Experimental Forest, 1969 to present - database code CP002 (https://doi.org/10.6073/pasta/2cee34b1d3c0836888444f9033c1c1c8).

d. Precipitation measurements from historic and current standard, storage and recording rain gauges at the H.J. Andrews Experimental Forest, 1951 to present - database code MS004 (https://doi.org/10.6073/pasta/6022898a200f7fac09aa36e79e0e66d7);
e. Meteorological data from benchmark stations at the H.J. Andrews Experimental Forest, 1957 to present - database code MS001 (https://doi.org/10.6073/pasta/c021a2ebf1f91adf0ba3b5e53189c84f).

Additional long-term complementary datasets are also publicly available, including:

1. Distributed snow depth and snow water equivalent measurements - database code MS007: https://doi.org/10.6073/pasta/ff5465b74f592e3114138a79d5cfe290.
2. Specific conductivity at 5 minute intervals at all gaged sites - database code CF012 (https://doi.org/10.6073/pasta/73b09502b3e6b0b2622f53810afa093b);
3. Annual measurement of bedload accumulation downstream of the stream gages at WS 1, 2, 3, 9, 10 - database code HS004 (https://doi.org/10.6073/pasta/73b09502b3e6b0b2622f53810afa093b);
4. Air temperature at climate stations throughout the Lookout Creek watershed - database code MS001 (https://doi.org/10.6073/pasta/c021a2ebf1f91adf0ba3b5e53189c84f);
5. Stream temperature and air temperature above the stream at gaged sites - database code HT004 (https://doi.org/10.6073/pasta/9437d1603044f5b92189110dd8343763);
6. Understory air temperature and soil temperature at Reference Stands - database code MS005 (https://doi.org/10.6073/pasta/d0abe716146004268bb5f876ee42c992);
7. Overstory and understory vegetation data from plots and transects - multiple database codes- see https://andrewsforest.oregonstate.edu/research/infrastructure/permanent-vegetation-plots.

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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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