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Perspectives on the contributions of women to the hydrologic sciences and their changing demographics at USDA Forest Service Experimental Forests and Ranges

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ABSTRACT

The increase in the frequency and severity of water crises around the world necessitates maintaining or augmenting investments in the hydrologic sciences, including in a trained, diverse workforce. The USDA Forest Service operates a network of 85 Experimental Forests and Ranges, Experimental Watersheds, and cooperating sites (EFRs), 31 of which include long-term hydrologic studies (HydroEFRs). The HydroEFRs are centers for hydrologic science and education and play a key role informing watershed policy and management. The goals of this study were to understand (1) how, broadly, the women associated with the HydroEFRs (including women in the Forest Service workforce and women with cooperating agencies or universities who have worked at HydroEFRs) have contributed to hydrologic sciences and (2) how, more specifically, the number and roles of women in the Forest Service workforce associated with the HydroEFRs have changed over time. Data were collected from the EFR Data Explorer, the USDA Forest Service Human Resources Management (HRM) Data Metrics and Analysis Team (DMAT), literature reviews, and questionnaires to USDA EFR scientists-in-charge and to women who were or had been involved in hydrologic sciences at EFRs. Results showed that women associated with the HydroEFRs have made significant contributions to the hydrologic sciences, including authoring or co-authoring over 3,000 publications, with over 170,000 citations since 1977 and an H-index of 181. In their own words, the women indicated that they were also active in contributing to hydrologic fieldwork, providing stewardship for long-term data, and contributing to the social capital of the HydroEFRs through teamwork, collaboration, and mentoring. For the Forest Service, trends in employment records from 1992 through 2021 showed a 55% contraction of the entire FS R&D workforce, including a 59% loss in the number of women in the FS R&D workforce, a 50% loss in the number of women associated with HydroEFR duty stations, and a 26% loss in the number of women in hydrology positions. During this period, there was a greater loss of both women and men in lower-graded positions relative to higher-graded positions in the FS R&D workforce, with serial implications for the ability of the workforce to collect data, produce basic science publications, and conduct syntheses. Although the ratio of women:men declined across the Forest Service and FS R&D, the ratio of women:men increased at the HydroEFRs (driven by a higher ratio of women:men at higher grade levels) and for management positions within FS R&D and at the HydroEFRs.When asked, women valued their contributions to the hydrologic sciences and envisioned a more equitable future for women in hydrology. Overall, results show that HydroEFRs have played an important role in advancing the careers of women in the hydrologic sciences, who, in turn, have contributed to the groundbreaking hydrologic research that occurs at these long-term research sites. As water

Abbreviations: DMAT, Data Metrics and Analysis Team; Deputy Area, One of five areas within the FS: National Forest System, State and Private Forestry, Research and Development, Business Operations, and Finance; DOI, Digital Object Identifier; EFR, Experimental Forests and Ranges; FS, Forest Service; GS, General Schedule; HRM, Human Resource Management; HydroEFRs, EFRs at which there is long-term hydrologic data/research; OPM, Office of Personnel Management; RGEG, Research Grade Evaluation Guide; R&D, Research and Development; SIC, Scientist-in-Charge; STEM, Science, Technology, Engineering, and Mathematics; USDA, United States Department of Agriculture; WoS, Web of Science.

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crises around the world continue to escalate, building a strong, diverse workforce in the hydrologic sciences and supporting the places where they can conduct their research is important.

1. Introduction

1.1. Water in a changing world

Water is one of the world's most important natural resources and clean and plentiful water is vital to people, agriculture, forestry, wildlife, transportation, industry, and recreation. Water quantity and quality on Earth is changing in myriad ways. For example, increasing populations and urbanization are placing more demands on local water supplies; increasing point and non-point source pollutants are contaminating water resources; human alterations including dams, fracking, irrigation, and draining of wetlands are altering local surface and subsurface water flows; and a changing global climate is modifying the amount, timing, distribution and phase of precipitation unevenly across the globe (e.g., Grafton et al., 2013; Taylor et al., 2013; Vörösmarty et al., 2010). As such, the need to support the hydrologic sciences and to maintain and grow a trained, diverse workforce to address water issues of today and the future has never been more important. The USDA Forest Service supports research in the hydrologic sciences and is committed to increasing the diversity of the workforce. In this paper, we explore the contributions of women to the hydrologic sciences at the Forest Service Experimental Forests and Ranges, the changes in the demography of women in hydrology at the USDA Forest Service, and consider future roles and directions for women in hydrology.

1.2. The USDA Forest Service supports hydrologic sciences

The USDA Forest Service (Forest Service), an agency within the Department of Agriculture, is one of the world's largest forestry organizations with over 39,000 employees in 2017 (Westphal et al., 2022). The Forest Service was established in 1904 with two primary missions: 1) to manage the nation's forests and 2) to secure reliable, clean water (Neary et al., 2012). In 1908, the Research and Development Deputy Area (FS R&D) was established, and in 1909 the first Forest Service catchment study was initiated (Ice and Stednick, 2004). Thus, research to support hydrologic sciences has been part of the Forest Service's mission since the agency's beginning. Although FS R&D is a relatively small part of the agency (~5% of total employees in 2017 (Westphal

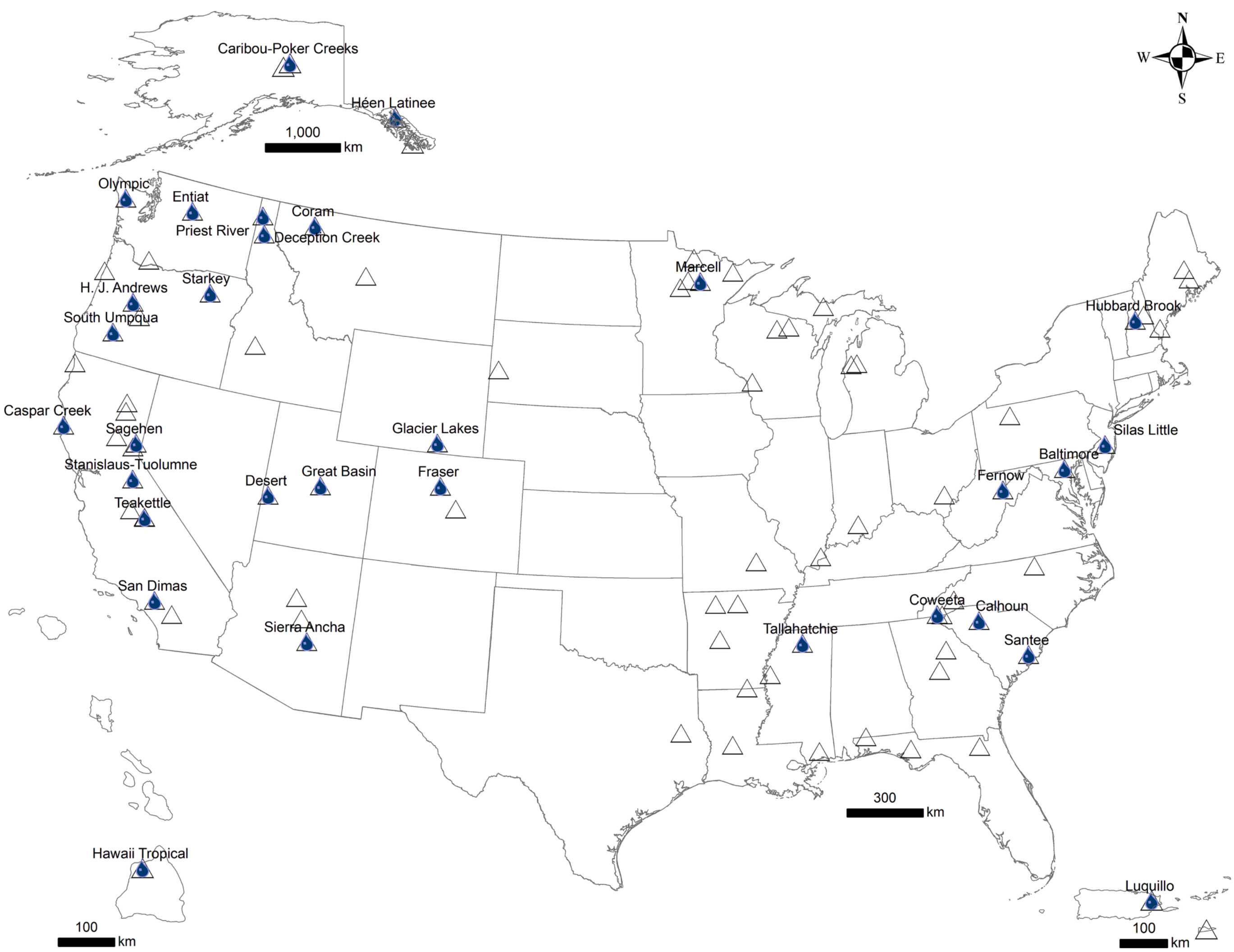

Fig. 1. Locations of the USDA Forest Service R&D 81 Experimental Forests and Ranges (EFRs), Experimental Watersheds, and four cooperating sites (triangles), and the 31 identified as HydroEFRs (HydroEFRs, blue inset within triangles) in the US. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

et al., 2022)), its workforce is broadly distributed, conducting research at five geographically-based research stations, as well as the Forest Products Laboratory, the International Institute of Tropical Forestry, and at the Washington, DC headquarters. Forest Service R&D also maintains and operates 81 Experimental Forests and Ranges and four cooperating sites (collectively call EFRs) distributed broadly across the US (Fig. 1). The EFRs represent the largest and longest-running hydrological and ecological research network in the US. This research network provides a wealth of long-term data (100+ years), and knowledge of ecological change, including hydrology, in natural and managed forest and grassland ecosystems across the US.

1.3. Major contributions of EFRs to hydrologic science

The US Forest Service EFRs have contributed significantly to the hydrologic sciences over the past century (Hayes et al., 2014; Wells et al., 2009), and the examples set by the EFRs are aspired to and emulated by researchers around the world (e.g., Deng et al., 2011; Kaste and Skjelkvåle, 2002; Norton et al., 1999; Wright and Jenkins, 2001). The EFRs are distinctive for (1) collection and maintenance of long-term, high-quality, place-based hydrologic, climatic, soils and vegetation data since as far back as the 1930s, which provide irreplaceable resources for the hydrologic science; (2) long-term watershed experiments, which have provided information on the initial and persistent effects of natural disturbance, pollution and forestry practices on streamflow and biogeochemical cycling; (3) the pioneering of new approaches, technologies and types of measurements in the hydrologic sciences; and (4) supporting inter-generational communities of researchers with long-term understanding of the places they are studying.

More specifically, early hydrological research at EFRs produced foundational knowledge on the response of streams, snowpack, and riparian biogeochemistry to forest management and land cover change (e.g., Hornbeck et al., 1970; Swank and Douglass, 1974; Troendle and King, 1985). More recent research has expanded our understanding of nutrient cycling (e.g., Brenner et al., 2006; Campbell et al., 2022; Feng et al., 2020), stream biogeochemistry (e.g., Bernhardt et al., 2002; Knoepp and Swank, 2002; Yanai et al., 2005), evapotranspiration dynamics (Ford et al., 2011a), soil water storage (Dymond et al., 2021; Jarecke et al., 2021), and ecosystem linkages to water resources (Ford et al., 2011b; Kelly et al., 2016). Experimental Forests and Ranges have also provided the basis for cross-site syntheses on controls on watershed chemistry and hydrology (e.g., Argerich et al., 2013; Creed et al., 2014; Jones et al., 2012); input to regional, national, and global assessments on water, climate, and pollution (e.g., McClain et al., 2003; Pörtner et al., 2022; Reidmiller et al., 2017; Rustad et al., 2012; Schlesinger et al., 2016; Shah et al., 2021); sites for major discoveries, such as the discovery of Acid Rain at the Hubbard Brook EFR, NH (Likens and Bormann, 1974), and commentaries on science and society (e.g., LaDeau et al., 2017a; Meyer et al., 2010; Weathers et al., 2021).

In addition to contributing to basic research, the "best available science" from EFRs has provided practical guidance on management and planning to the National Forest System, and State, Federal, and International agencies and organizations (e.g., Clare and Creed, 2022; Coble et al., 2020; Creed et al., 2011; Creed et al., 2014; Elliott et al., 2017; Ford et al., 2011b; Kelly et al., 2016; Wells et al., 2009); and has informed major state and federal environmental legislation including the Clean Air Act and its amendments, and the Clean Water Act (McClain et al., 2003; Vose et al., 2014; Wells et al., 2009). Finally, EFRs also serve as major centers for education and outreach in the form of demonstration projects, tours, and student and early career scientist training (Vose et al., 2014; Wells et al., 2009). In all, the EFRs have been powerhouses for hydrologic science and education in the US over the past century, and continue to play a key role hydrologic science and informing watershed policy and management.

1.4. The importance of a diverse workforce

A growing body of knowledge shows that workforce diversity of race, ethnicity, and gender fosters innovation, improves performance, and leads to more effective problem solving (Cheruvelil et al., 2014; Nielsen et al., 2017; Østergaard et al., 2011; Rice, 2011). A more heterogeneous workforce is also more relevant to the diverse communities they serve (Batavia et al., 2020). More specifically, gender diversity is recognized as an important factor for creating a healthy work environment in research groups and at workplaces because women, men, and non-binary individuals bring a multiplicity of thought processes and interpersonal skills to their workplaces (Nielsen et al., 2018; Popp et al., 2019). Despite the high value increasingly placed on diversity, women remain underrepresented in science, technology, engineering, and mathematics (STEM) fields, especially in the geosciences (of which hydrology is a subdiscipline), and at more senior roles. Further, studies show that women in science are often the subject of more harassment and more hostile work environments than men in science (Gonzales, 2019; Mattheis et al., 2022; Wilson, 2017), and are more often the subject of overt or subtler gender discrimination (Kern et al., 2020). Overcoming these and other barriers (e.g., Berhe et al., 2022; Marín-Spiotta et al., 2020) to increasing the participation of women in STEM is critical to meeting the socio-ecological challenges, including threats to water resources, that we face in the 21st century.

1.5. Women in the Forest Service: still an underrepresented group

The Forest Service is committed to diversity in the workplace. The agency's vision statement is: "*We are a multicultural and diverse organization. … All employees are respected, accepted, and appreciated for their unique and important contribution to the mission*" (USDA Forest Service, 2022). Despite decadal-scale efforts, the numbers of women in the Forest Service as a whole, and in FS R&D specifically, still lag behind those of men. In 2017, women represented 34% of the entire Forest Service workforce and 41% of FS R&D, (Westphal et al., 2022). Across the entire Forest Service, the percentage of women in senior-level, mid-level and entry level positions was 42%, 40% and 29%, respectively (Westphal et al., 2022). Although not equitable with men, the outlook was better than for other areas of STEM. For example, the percentage of women in senior-level positions in the Forest Service in 2017 (42%) was higher than that reported for women in faculty positions in the geosciences at US universities in 2015 (19% of total positions) (Wilson, 2017). The need to hire, support and promote women in the environmental sciences at all levels to achieve equal representation with men, clearly, still exists.

1.6. Who are the women who have contributed to the hydrologic sciences at EFRs?

Although women may not have been involved in the early establishment of EFRs, they have been essential in maintaining these long-term studies (Green et al., 2021; See et al., 2020), ensuring the integrity and quality of the data, (Edwards et al., 2019; Edwards et al., 2016; Lany et al., 2018; Laseter et al., 2012), developing new forms of analysis and synthesis (e.g., Rustad et al., 2001; Ryan et al., 2002), and discovering new findings as the hydrology of forested ecosystems has changed over time (e.g., Adams et al., 2014; Dwire and Mellmann-Brown, 2017; Eggert et al., 2020; Johnson et al., 2022; Knoepp et al., 2016). More recently, women have also assumed leadership roles at EFRs as exemplified by MaryBeth Adams, Project Leader at the Fernow EFR (1990 to 2011), followed more recently by Melissa Thomas Van Gundy (2022 to present); Lindsey Rustad, Team Leader at Hubbard Brook EFR (2007 to 2022); Sherri Johnson, Team Leader at HJ Andrews EFR (2010 to 2022), followed by Brooke Penaluna (2022 to present); Chelcy Ford Miniat, Project Leader at Coweeta Hydrologic Laboratory (2012 to 2019); and Grizelle Gonzales, Project Leader at Luquillo EFR (2012 to present).

Previous studies have examined gender representation in the FS R&D

(Kern et al., 2015), and specifically the role of discrimination and harassment on job satisfaction within FS R&D (Kern et al., 2020). More recently, work has been conducted on Forest Service employee diversity during a period of workforce contraction (Westphal et al., 2022). Here, our goal was to understand how women have contributed to the hydrologic sciences at Forest Service EFRs and how their role has changed over time. We include women employed by the Forest Service who work at EFRs at all career levels, as well as those women scientists, technicians, and other staff from cooperating agencies and universities who have been instrumental to advances in hydrologic, watershed science, and/or stream biogeochemical research at EFRs. Specifically, we asked: 1) how have the women of hydrology at EFRs contributed to hydrologic sciences; and 2) how have the number and roles of women at employed specifically by the Foret Service at EFRs changed over time? We end with briefly summarizing, in their own words, how the women of hydrology at EFRs view their past and aspire for the future.

2. Methods

This study is based on data collected from an online EFR Data Explorer, the USDA Forest Service Human Resources Management (HRM) Data Metrics and Analysis Team (DMAT), literature reviews, and questionnaires.

2.1. Identify EFR sites with hydrologic research programs

We used the EFR Data Explorer to identify EFRs where the most recent scientist-in-charge (SIC) of the EFR had self-reported that some type of hydrologic data had been collected at their EFR (hereafter "HydroEFRs"). We defined hydrologic data as data collected on precipitation (rainfall or snowfall), streamflow, evaporation, transpiration, groundwater, and/or soil moisture. The EFR Data Explorer is an online tool documenting major foci of research at the EFRs (USDA Forest Service, 2022).

2.2. Identify women who have contributed to hydrologic sciences at HydroEFRs

We identified women who had contributed to the hydrologic sciences at HydroEFRs by first emailing the SIC for each of the HydroEFRs identified by the EFR Data Explorer. They were asked to identify women who worked for the Forest Service or for universities or other Agencies who had 1) spent a considerable portion of their career working at the SIC's EFR and who had 2) made contributions to advance hydrologic science. These names are otherwise available (but hard to find) on publicly-facing websites associated with EFRs or can be found as authors, co-authors, or in acknowledgment sections of publications associated with EFRs. We defined the hydrologic sciences broadly as hydrology, watershed sciences, and stream biogeochemistry. Specifically, we asked each SIC to provide information on women in eight categories. We asked for information on if such women existed and, if yes, what their names were. The categories included:

1. Forest Service women scientists currently working at the EFR
2. Forest Service women technicians/staff currently working at the EFR
3. Forest Service women scientists who had worked at the EFR in the past
4. Forest Service women technicians/staff who had worked at the EFR in the past
5. University or other Agency women scientists currently working at the EFR
6. University or other Agency women technicians/staff currently working at the EFR
7. University or other Agency women scientists who had worked at the EFR in the past
8. University or other Agency women technicians/staff who had worked at the EFR in the past

Scientists included Federal Government Research Grade Level 13–15 and 0 (ST) equivalent scientists for government agencies and co-principal investigators or collaborating scientists (typically tenured or tenure-track scientists or equivalents) for academic institutions. Technicians and staff included field technicians, information managers, laboratory staff, and others who spent a significant portion of their time assigned to the EFR. It was important to gather this information from the SIC, as not all women who contribute to the hydrologic sciences at EFRs are classified as hydrologists (Office of Personnel Management (OPM) series 1315) or hydrologic technicians (OPM series 1316) in the Forest Service employment database, and it can be difficult to identify the many collaborating scientists and staff from universities, NGOs, and other agencies who work at the EFRs. We were purposefully vague on a specific metric of contribution, such as years of service or numbers of publications, as the contributions varied widely across the EFRs. We wanted to include "unsung heroes" whose works might be critical for the success of the EFR, but whose names may not appear in journal articles or other more traditional forms of professional acknowledgment. We did not ask about administrative staff in this compilation, although we recognize and laud the critical support role they provide.

2.3. Contributions of women at EFRs to the academic literature of hydrology and Hydrology-related sciences

We used the Web of Science (WoS) search tool to conduct a literature review on the names in our compilation of women of hydrology associated with HydroEFRs though 2021. Each name was entered into the Researcher Name Search bar, and search results were checked to confirm that published names included the correct variations of researchers' names (including known maiden names or hyphenated names), that publications were related to hydrology or environmental sciences, and that researchers from other fields that shared the same or similar common name were excluded. The resulting list of authors and publications was saved as a WoS Marked List. Web of Science tools were used to summarize the publications in the Marked List for total number of academic publications, the total number of citations, the H-index, and the number of academic publications by WoS research category, journal, affiliation, and funding agency. The H-index is equal to the number of papers (N) in the list that has N or more citations. The WoS is a useful database, but it is noteworthy that it is not complete as it may exclude some publications by some authors and it is possible that it includes some publications of women with the same names as those on our list but who are not associated with the HydroEFRs.

2.4. DMAT: USDA Forest Service women in the hydrologic pay series

Although demographic data are not available for the entire hydrologic work force across the country, such data are available for the USDA Forest Service. We sought to understand how the numbers of women in the Forest Service as a whole and in FS R&D had changed since last reported for the period 1995 to 2017 by Westphal et al. (2022). We also wanted to understand more specifically how the numbers of women and men associated with HydroEFRs and in the hydrologic occupational series (1315 and 1316) had changed over time. Following methods similar to Westphal et al. (2022), we obtained data from the personnel history data table from the Forest Service's Human Resources Management (HRM) Data Metrics and Analysis Team (DMAT). Digitized data are available and reliable for this data table for each pay period (or two weeks) for each employee from 1992 through 2021. We pulled data from the single Pay Period 19 (mid-September) to generate one annual sample for thirty years of records for each anonymized person employed during that specific pay period. Employees not employed during that pay period were missed; for example, summer seasonal employees would likely have been underrepresented. The data for each anonymized individual included: fiscal year (FY), the organizational code (which contains information on Deputy Area, Research Station, Region, and Program or Project unit), grade or General Schedule Classification (GS-level), gender, position title, OPM occupational series, supervisory code, duty station location (city and state), and pay plan.

To make inferences on grade level, we filtered data by GS-level and categorized GS-levels 1–8 as lower, 9–12 as mid, and 13–15 and 0 as upper graded positions. While grade and wage are positively correlated, grade and career stage are not. Executives and Senior Scientists occur in the database as grade 0. To make inferences regarding hydrology, we filtered data for the 1315 (hydrologist) and 1316 (hydrologic science technician) occupational series by gender, FS R&D versus non-FS R&D, and year. To make inferences regarding women at EFRs, we asked the SICs at each HydroEFR to identify the primary duty station locations associated with their sites. SICs at seven EFRs identified multiple primary duty stations associated with their EFR. In all, we had 41 duty locations identified as associated with the 31 hydroEFR locations. These duty station locations were used to create a new variable, "EFR," which assigned EFR duty stations as "EFR" and all other duty stations as "non-EFR." We recognize that not all individuals at these assigned EFR duty stations work at the EFR, particularly at the larger duty stations. Similarly, we also recognize that individuals at other duty stations are affiliated with EFRs and their location may not have been identified by the SIC. To make inferences regarding supervisory status over time, we coded a new variable "Sup" that included all records as supervisor, manager, and leader, including those meeting the legal definition of supervisor in the Civil Service Reform Act (CSRA) and those not meeting the legal definition but having supervisory duties and defined them as "supervisors." Those listed as non-supervisory were coded "non-supervisors."

To test for significant linear trends over time, we used fiscal year as a continuous variable predicting the number of employees over time and used gender as a covariate. To test for differences in slope and intercept, we fit a general linear model to the data and used custom contrasts to test for differences in slope and intercept for gender according to Zarnoch (2009) (PROC GLM SAS v9.4). All residuals were tested for significant autocorrelation (PROC ARIMA SAS v9.4), and while significant autocorrelation was found in most residual series, the pattern appeared in most every series, and had a similar cyclical pattern; thus, we feel inferences across regressions are robust.

2.5. Women of hydrology at EFRs questionnaire

We wanted to hear from the women themselves, in their own words, about their experiences working at the EFRs. Our goal was not to conduct social science research but rather to provide an historical perspective on women in the hydrologic sciences who worked at EFRs by asking them to tell us about their experiences. To do this, we sought email addresses from publicly available sources for the women whose names had been provided by the SICs. We were not able to find email addresses for all the women, especially those that had retired. For those with emails, we contacted each one (in accordance with the Paperwork Reduction Act), described the project, and invited them to fill out a questionnaire on "Past, Present and Future Women in Hydrology at EFRs," asking them about: how they viewed their contributions to the hydrologic (and other) sciences (multiple choice and open-ended questions); their networks and interactions with other women at their EFRs (multiple choice questions); whether they had a woman as a mentor and what this meant to them (multiple choice and open-ended questions); a favorite memory of working at their EFR (open-ended question); how they perceived the roles of women in hydrology changing at their EFR over the past 50 years (open-ended question); and, what their vision was for women in hydrology at their EFR for the future (open-ended question; questionnaire in supplementary materials). We explained that responding to the question was voluntary, and the identities of women responding to the questionnaire would be anonymous. We tabulated the answers to multiple choice questions. For the open-ended questions, we developed categories based on the respones, assigned the responses to the categories, and tabulated the results (Woike, 2007).

3. Results and discussion

3.1. The HydroEFRs

Studies of hydrologic and watershed processes were major components of work at the time of establishment at several EFRs (e.g., Coweeta Hydrologic Laboratory, NC: Hubbard Brook EF, NH; San Dimas EF, CA; HJ Andrews, OR) (Gottfried et al., 2014), and by 2008, fifteen EFRs were considered "watershed EFRs" by Vose et al. (2014). However, many other EFRs collect hydrologic and watershed data as part of their ongoing research. Using the EFR Data Explorer (USDA Forest Service, 2022), we identified 39 EFRs that self-identified as having collected some type of hydrologic data since their establishment. Of these, we excluded eight EFRs because the data were of limited scope (e.g., precipitation data only) or extent (e.g., collection period less than ten years). The 31 EFR sites with hydrologic data (HydroEFRs) are broadly distributed across the US (Fig. 1).

3.2. Who are the women who have contributed to hydrologic sciences at HydroEFRs?

A large number and diversity of women from across the country, representing different scientific fields, occupations, career stages, and agencies and institutions, have contributed to the hydrologic – and other – sciences at HydroEFRs. The SICs from all 31 HydroEFRs provided information on women in hydrology at their EFR. From these responses, we created a compilation of 180 women associated with the HydroEFRs. We recognize that some SICs had better knowledge of current and past scientists, technicians, and cooperators than others, some were more willing than others to consult peers or review past documents from their EFRs to identify the women of hydrology at their EFRs, and none had complete knowledge of all the women who had contributed to the hydrologic sciences at their EFR. Thus, our compilation is an underestimate of the number, names, and roles of women at these HydroEFRs, and we apologize to those women whose names have not been recognized. Despite these caveats, this compilation does represent a cross-section of Forest Service and collaborating scientists, technicians, and staff who are contributing or have contributed to hydrologic sciences at these EFRs (Fig. 2). Several observations about these women include:

- Thirty-nine percent of the women worked or had worked for the Forest Service, and 61% worked or had worked for universities or other agencies. The large number of women from non-Forest Service organizations shows that HydroEFRs serve an important role as research and training grounds for women in hydrology across the US, and not just within the Forest Service.
- Sixty percent of the women were scientists; 40% were technicians or staff. This highlights the contributions of women of all levels (not just scientists) to hydrologic sciences at these sites.
- The women were divided nearly equally between those that currently work at HydroEFRs (53%) and those that had worked at HydroEFRs in the past (47%). The percentages were similar for scientists and technicians/staff. This may reflect the SICs knowledge of women currently working at their HydroEFR vs. those in the past or could reflect an increase in the percentage of women working at the HydroEFRs now compared to the past.

3.3. What are the contributions of women at HydroEFRs to the academic literature of hydrology and hydrology-related sciences?

Women associated with HydroEFRs have contributed to a substantial

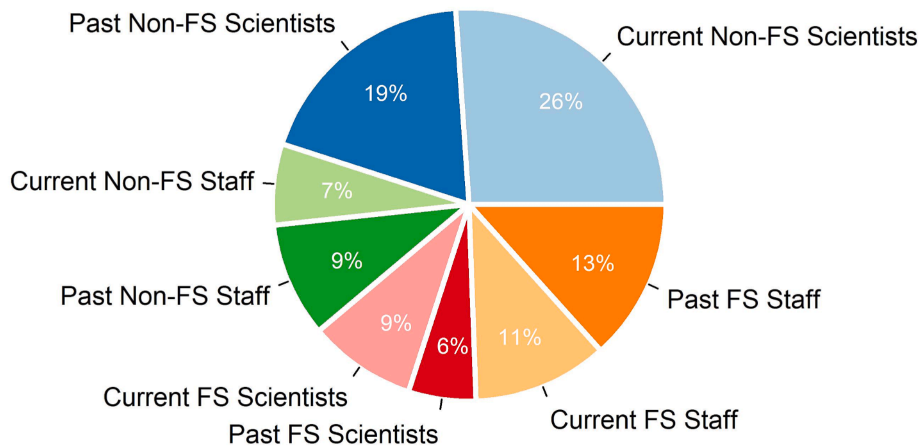

Fig. 2. Number of women and percent of total women out of 180 identified at HydroEFRs in eight categories.

and diverse body of research over the past 45 years. Of 180 names of women associated with HydroEFRs, we were able to find publications for 136 (76%) on the WoS. Given that scientists represented 59% of the total number of women in our compilation (Fig. 2), this shows that women in science-support roles (41% of compilation) were contributing to the published literature alongside scientists. Examples of these contributions include those by field technicians (Green et al., 2021; See et al., 2020), Information Managers (Edwards et al., 2019; Edwards et al., 2016; Lany et al., 2018; Laseter et al., 2012), chemists (Brown et al., 2021), and laboratory physical scientist technicians (Hislop and Hornbeck, 2002).

Women of HydroEFRs were prolific publishers. For the 136 women with publications on WoS, we identified a total of 3,099 publications for the period 1977 to 2021, which had been cited 174,642 times, with an H-index of 181 through 2021 (Fig. 3). Not all of these publications are based on research from the author's HydroEFRs. However, HydroEFRs, as places to conduct long-term research and monitoring and as communities of scientific practice, likely helped shape the careers and research of these women, and hence contributed directly or indirectly to these publications. Conversely, research of these women conducted elsewhere may have shaped the direction of their work at the HydroEFRs. It is noteworthy that the early papers in our review were published in the late 1970s (Meyer, 1979; Meyer and Likens, 1979), which was 70 years after the establishment of the first EFR in 1909. We suggest this could be due to the SICs not having known the names of earlier women pioneers at EFRs, that women were not generally encouraged nor supported to publish during the early years of the EFRs (Kline, 2021), or that few women worked at these sites prior to the 1970s.

The large number of publications reinforces that HydroEFRs are important research and training sites for women across the US. Although results for the top 15 affiliations showed that 29% of the publications were co-authored by scientists affiliated with USDA, 15% were co-

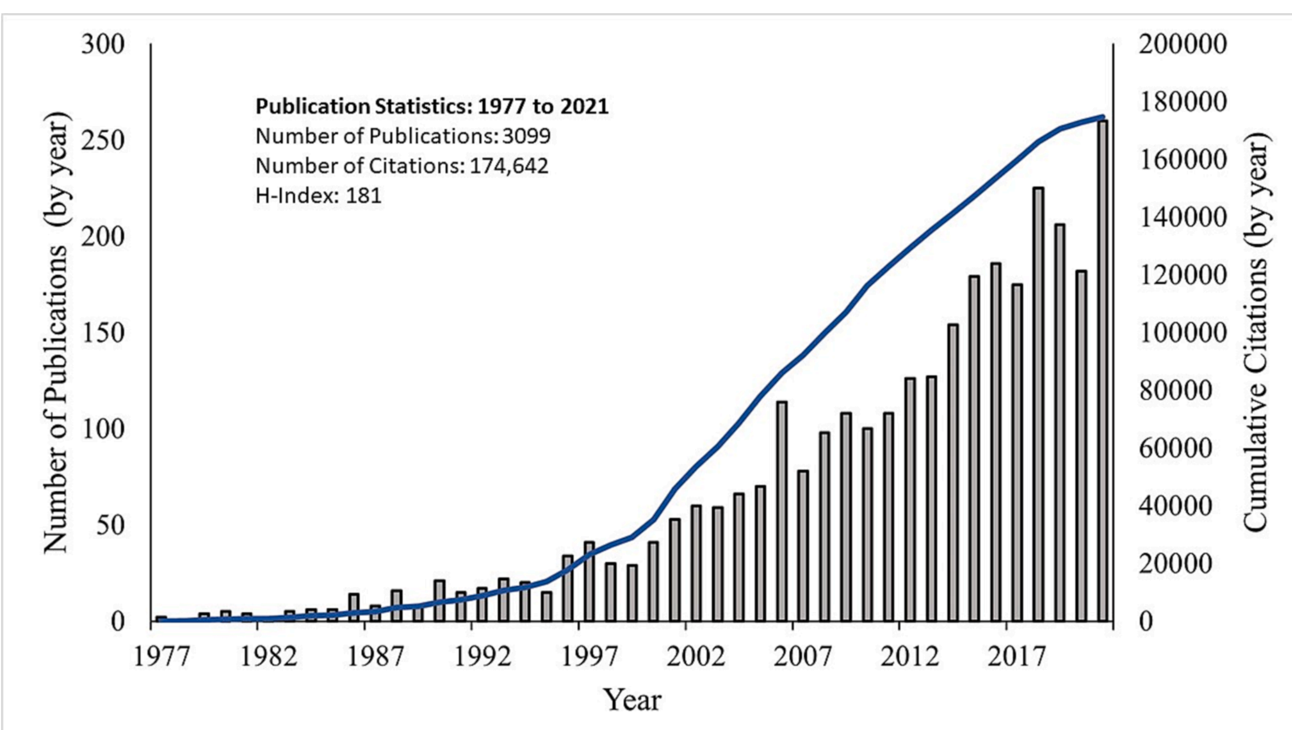

Fig. 3. Numbers of publications (bars) and citations (blue line) for women of Hydro EFRs by year from 1965 to 2021 as compiled from WoS results. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

authored by scientists affiliated with other federal agencies, and 55% were co-authored by scientists affiliated with academic institutions (Fig. 4).

The women of HydroEFRs have been publishing across a broad range of environmental and hydrologic disciplines. Of the top 15 WoS categories, 22% of the publications were categorized as Environmental Science, 19% as Ecology, 10% as Geosciences, 9% as Water Resources, and 40% as other watershed science-related fields (Fig. 5). This range of disciplines is further reflected in the diversity of journals where the women were publishing (total of 487 journals), which include *Biogeochemistry*, *Forest Ecology and Management, Hydrologic Processes*, *Water Resources Research*, *Ecology*, *Ecosystems* and more (Fig. 6). Collectively, the women have co-authored 16 publications in *Science*, 15 in *Nature*, and ten in *Nature Geoscience.*

The research has largely been funded by the US federal government. Of the top 15 WoS funding agencies, roughly half of the publications (52%) acknowledged the National Science Foundation as a funding source. Nineteen percent, 14%, and 16% acknowledged the USDA, other federal agencies, and international organizations, respectively (Fig. 7). It is noteworthy that it has not always been the standard to acknowledge the organization, such as the USDA Forest Service, responsible for funding the long-term datasets and/or research sites that are foundational to research papers. This is changing, as scientists are routinely expected to publish data in publically accessible archives with unique digital object identifiers (DOI), and as more research sites have provided standardized acknowledgements to authors. For example, all research manuscripts published using foundational data produced by the Hubbard Brook Experimental Forest in NH can cite a DOI for the underlying data and are expected to include the acknowledgement: "The Hubbard Brook Experimental Forest is operated and maintained by the USDA Forest Service, Northern Research Station, Madison, WI (1014507, 1114804)." It is also noteworthy that in this analysis, we include all the papers from a female scientist that has worked at an HydroEFR, assuming that the scientist has been influenced by the HydroEFR or the scientist's work has, in turn, influenced the work at the EFR. Thus, work funded elsewhere, by other organizations not supporting the HydroEFRs, are included.

Although it is beyond the scope of this paper to produce an annotated bibliography of these publications, selected highlights include the foundational work on nutrient cycling and metabolism in streams by Judy Meyer (Meyer, 1979; Meyer et al., 1988; Meyer et al., 1998); the impacts of acidic deposition on surface waters by Mary Beth Adams (Adams et al., 1993; Adams et al., 1997), Pamela Edwards (Edwards et al., 2002a; Edwards et al., 2002b), and Lindsey Rustad (Rustad et al., 1993); long-term trends in hydrology and implications for management by Sherri Johnson (Johnson et al., 2021; Johnson and Jones, 2000); instream processing of nitrogen by Emily Bernhardt (Bernhardt et al., 2003; Bernhardt et al., 2002), novel surface water pollutants such as pharmaceuticals by Emma Rosi (Rosi-Marshall et al., 2015; Rosi-Marshall and Royer, 2012); topographic, edaphic, and vegetative controls on plant-available water by Salli Dymond (Dymond et al., 2017) and controls on streamflow generation in small catchments by Carol Hunsaker (Hunsaker et al., 2012; Liu et al., 2013). Women have also led cross-site syntheses such as on trends in stream nitrogen in catchments across the USA by Alba Argerich (Argerich et al., 2013), on regulations of streamflow response to climate change at Long-Term Ecological Research sites by Julia Jones (Jones et al., 2012), and on climate change impacts on forest water yield at long-term experimental watersheds across North America by Irena Creed (Creed et al., 2014). In addition to basic research, women at HydroEFRs have provided practical guidance on management and planning such as the work on water yield following forest-grass transitions by Katharine Elliot (Elliott et al., 2017), on whether management can sustain water-based ecosystem services in the face of climate change by Chelcy Ford Miniat (Ford et al., 2011b), and the work on ecohydrological disturbances associated with roads by Beverley Wemple (Wemple et al., 2017; Wemple and Jones, 2003). Finally, women at the HydroEFRs have contributed to commentaries on science and society such as envisioning the next decade of big data in environmental sciences by Kathleen Weathers and Emma Rosi (LaDeau et al., 2017b), unraveling issues of the peer-review process by Kate Lajtha (Lajtha, 2019; Lajtha and Baveye, 2010), frontiers in ecosystem ecology and leveraging the Anthropocene by Kathleen Weathers (Weathers et al., 2016; Weathers et al., 2021) and even integrating art and science as in the work of Lindsey Rustad (Rustad et al., 2018).

Although impressive, we remind the reader that this compilation is an underestimate of the contributions of women to the hydrologic and environmental sciences at HydroEFRs because the current SICs likely had incomplete knowledge of all the women who had contributed over time to their EFRs, and the WoS has an incomplete listing of all the publications for all the women.

3.4. *The changing forest service workforce*

Understanding demographic trends across the nation's hydrologic workforce can help agencies and institutions plan for a more equitable, diverse and productive future. Although centralized demographic data

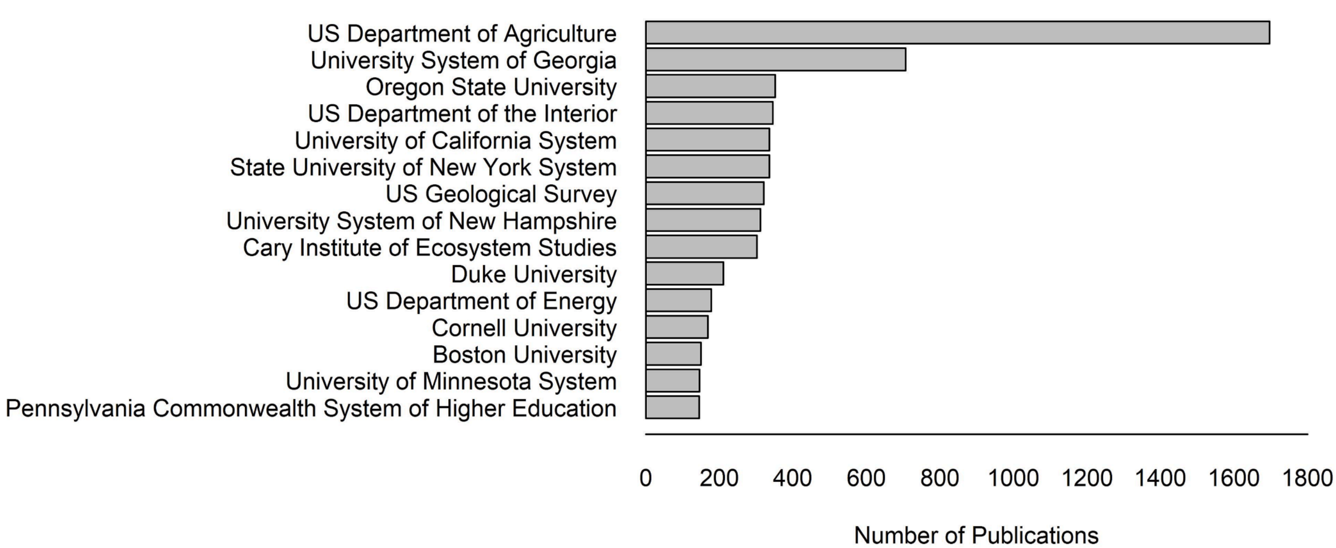

Fig. 4. Top 15 affiliations for the 3,099 publications of Women of EFR Hydrology.

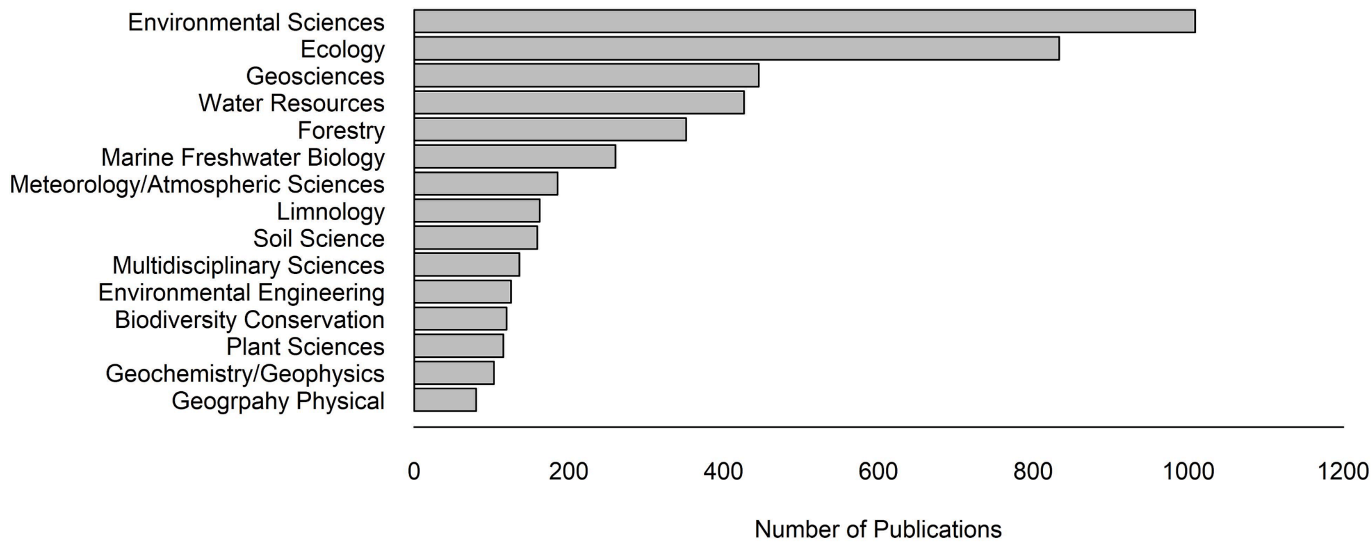

Fig. 5. Top 15 WoS categories of disciplines for the 3,099 publications of Women of EFR Hydrology.

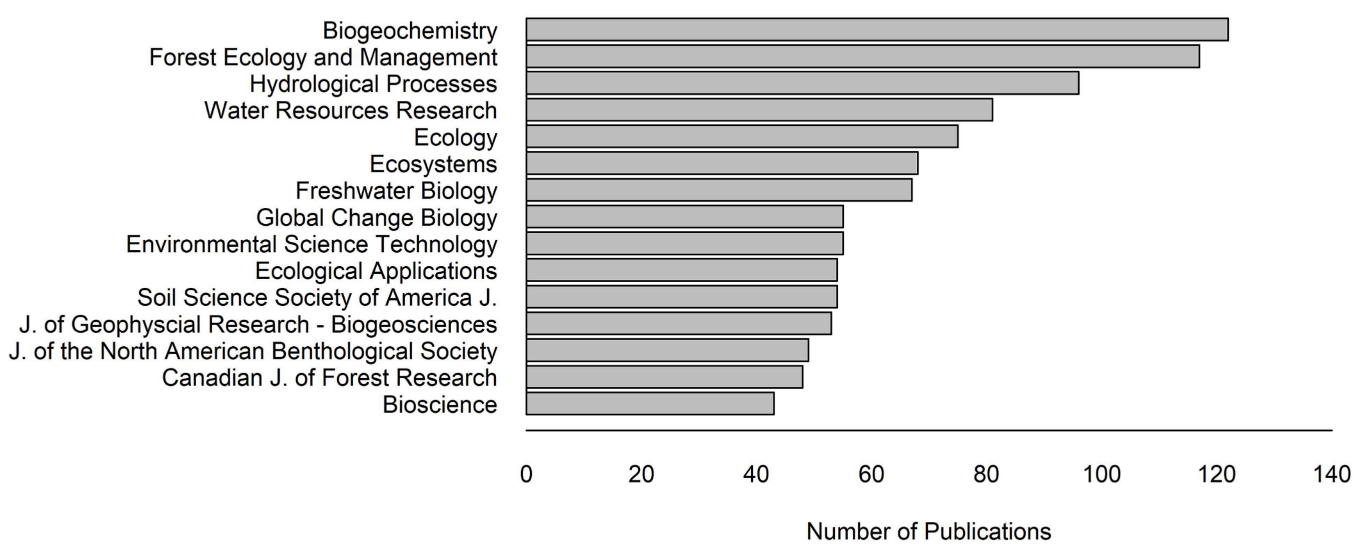

Fig. 6. Top 15 WoS categories of journals for the 3,099 publications of Women of EFR Hydrology.

from organizations across the country are not available, such data are obtainable from the USDA Forest Service, one of the largest environmental employers in the nation. Identifying the women and men who worked at HydroEFRs is challenging as no single Forest Service identifier exists for the EFRs or the hydrologic workforce within the EFRs. The diverse EFR workforce which contributes to hydrologic research includes hydrologists (series 1315), hydrologic technicians (series 1316), ecologists (series 0408), foresters (series 0460), forestry technicians (series 0462), geologists (series 1350), biologists (series 0401), physical scientists (series 1301), and others. To explore gender trends, we present perspectives on changes in the Forest Service as a whole, the FS R&D deputy area within the FS, the HydroEFRs (as defined by duty stations) within FS R&D, and the hydrology series positions within FS R&D. Discussions are based on modelled trends and not absolute values.

3.4.1 Overall Decline in Workforce: The Forest Service workforce is large, but it has declined significantly (–23%) over the last 30 years (Table 1, Fig. 8A). The FS R&D workforce declined more over the last 30 years (–55%) than the non-R&D workforce (-20%) (Table 1). Within FS R&D, the workforce at HydroEFR-associated duty stations declined by –53% compared to all other duty stations (–57%). There are very few hydrologists and hydrologic technicians in FS R&D (2–3% of FS R&D), and these employees have declined over the last 30 years by –39%. These trends represent a significant loss of scientific capacity in general, and a significant loss of scientific capacity in the hydrologic sciences specifically, within FS R&D.

3.4.1. *Changes in workforce over time by gender*

Despite decades of change (Westphal et al., 2022), the Forest Service remains majority male, with about twice as many men compared to women as of 2021 (Table 2). For the entire Forest Service, the rate of workforce decline (e.g., slope of trend line) and the absolute numbers of positions lost over the last 30 years were similar by gender (Table 2). However, because the total number of women in the Forest Service was smaller, this resulted in a larger percent decline for women (−31%) vs. men (−19%; Fig. 8A) and a significant decline in the ratio of women: men, from 0.61 in 1992 to 0.50 in 2021 (Table 3, Fig. 9). Within FS R&D, the number of women in the workforce declined significantly more than men in the workforce (−59% for women vs., 53% for men; Fig. 8B). This resulted in a significant decline in the ratio of women:men from 0.73 in 1992 to 0.68 in 2021 (Table 3, Fig. 9). Within the Hydro-EFR duty stations, the percent loss of women in the workforce was less than the percent loss of men (−50% vs. −56%), resulting in a significant increase

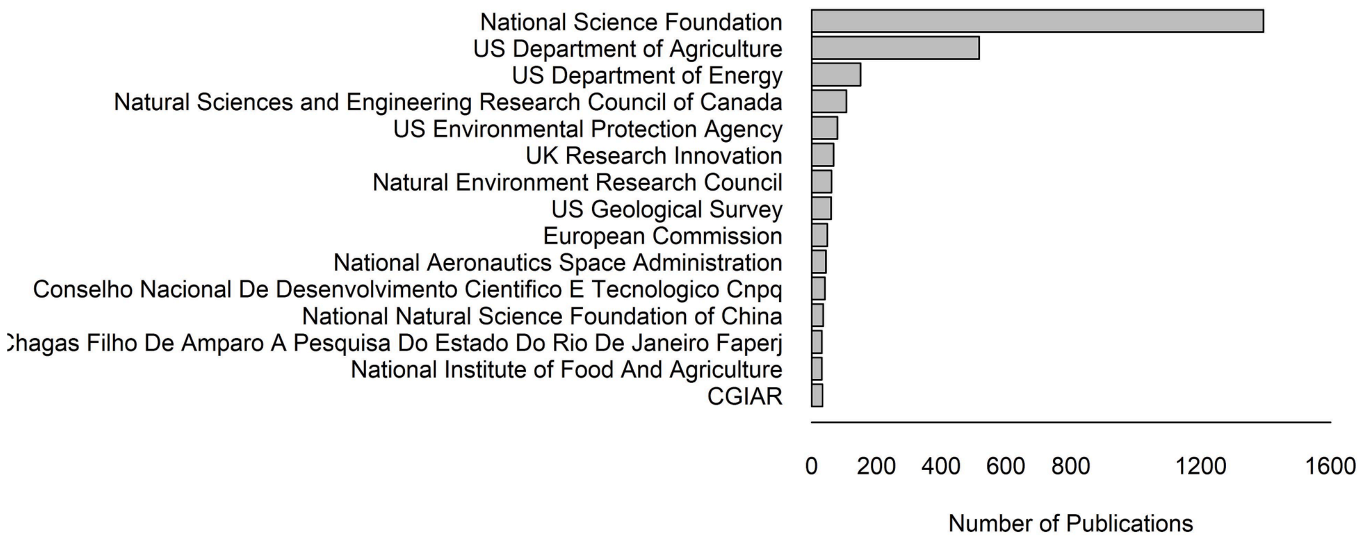

Fig. 7. Top 15 WoS funding agencies for the 3,099 publications of Women of EFR Hydrology. (note: 40% of publications did not contain data for funding agencies).

in the ratio of women to men, from 0.68 in 1992 and 0.79 in 2021 (Table 3). The positions in the relatively small hydrology-series workforce in the FS R&D are mostly held by men (Table 2, Fig. 8C). Within these hydrology positions, the number of women declined less than men in the workforce (−26% for women; −43% for men), but this did not result in a significant increase in the ratio of women:men over time (Table 3).

3.4.3 Changes in Workforce Over Time by Grade Level and Gender: Most of the workforce declines since 1992 occurred in lower-graded positions. These lower-graded positions declined by −27% across the entire Forest Service, by −82% in FS R&D, by −79% at HydroEFRs, and by –33% for the hydrology-series workforce (Table 1). The mid-graded positions were the next most lost positions, at –24%, –34%, −36% and −52% across the entire Forest Service, FS R&D, the HydroEFRs, and hydrology-series workforce, respectively (Table 1). For the higher-graded positions, there was no significant change in the numbers of these positions over time across the entire Forest Service. However there was a −35%, −26%, and −27% loss in these positions in FS R&D, the HydroEFRs, and the hydrology-series workforce, respectively (Table 1). We suggest caution on interpretation of the hydrology series data due to low numbers.

More women than men were lost in the lower-graded positions across the entire Forest Service (–59% women vs. –1% men), in FS R&D (–85% women vs. –77% men), at the HydroEFRs (-80% women vs. −78% men), and in the hydrology-series positions (-61% women vs. –23% men) (Table 2). The number of women in higher-graded positions increased and the number of men in higher-graded positions decreased across the entire Forest Service (+126% women vs. −28% men), in FS R&D (+33% women vs. −49% men), at the HydroEFRs (+54% women vs. −42% men), and the hydrology-series positions (+331% women vs. −50% men). The ratio of women:men in higher-graded positions at the HydroEFRs increased from 0.17 in 1992 to 0.50 in 2021 (Table 3). Overall, this shows an increase in the number of senior women in the FS R&D hydrologic workforce.

It is noteworthy that the increase in the number of women in the higher-graded positions is concomitant with the loss of support at the lower- and mid-graded positions. This could suggest that women who currently occupy the higher-graded positions are either performing more basic research and administrative tasks than their earlier men and women counterparts (e.g., more sample measurements, data analyses, administration, etc.), or conducting more synthetic science- vs. basic science-related research. Our bibliographic data suggests the latter may be true, as there were no publications from 1992 through 2000 with synthesis-related key words (e.g., “synthesis”, “meta-analysis”, “meta-regression“), and fifteen publications with synthesis-related key words between 2001 and 2021. If the trend for loss of women and men in lower-graded positions continues, generating basic science from new data collection may be diminished, reducing basic science publications and our ability to conduct synthetic work in the future. The loss of women in the lower positions also suggests a diminishing internal pool of applicants (i.e., “pipeline”) for advancement to mid- or eventually higher-graded positions.

3.4.4 Changes in Workforce Over Time by Supervisory Position and Gender: As with the overall workforce, the proportions of managers across the entire Forest Service and in FS R&D were predominantly male in 2021 (71% and 61%, respectively; Table 2). During the period 1992 to 2021, the number of managers did not change significantly across the entire Forest Service or at the HydroEFRs but declined by –32% in FS R&D. In FS R&D, the number of women managers declined less than men managers (−12% and −41%, respectively). The relationship between the change in the number of managers vs. the change in workforce resulted in an increase in the number of managers per capita across the Forest Service (0.26 managers per capita in 1992 to 0.31 managers per capita in 2021), and FS R&D (0.24 managers per capita in 1992 to 0.30 managers per capita in 2021). The increase in managers per capita in FS R&D was mostly driven by an increase in the number of women managers per capita (0.07 women managers per capita in 1992 to 0.12 women managers per capita in 2021). This shows a small improvement in the role of women as managers in the FS R&D.

3.4.5 Summary of Workforce Changes and Suggestions for Future Research: Taken together, these results suggest there has been an overall loss of women across the nested categories from the entire Forest Service to the hydrology-series positions, and that these losses were greatest in the lower-graded positions. At the same time, the proportion of women at higher-grade levels increased — across the nested categories from the entire Forest Service to the hydrology-series positions and the proportion of women managers increased — demonstrating an overall increase in the proportion of women in leadership positions. Although our historical data do not permit us to analyze the causes or impacts of these trends, it is likely that these women in leadership roles serve as role models for other women in the Forest Service and the broader scientific community, increase sensitivity of Forest Service leadership to gender-based issues such as wage equity, workplace safety, and accommodations for family and gender-based medical leave, and bring their unique perspectives to research and management agendas. We suggest that investigating these impacts is a fertile area for future research. We also

Table 1
Total numbers of employees for pay period (PP) 19 in 1992 and 2021 for all of the Forest Service (FS) and for the Research and Development (R&D) and non-R&D deputy areas. Hydro Series is a category containing hydrologists and hydrologic science technicians (1315 and 1316 OPM series). Linear regressions predicting the number of employees (y) by fiscal year (x = FY) are presented. All slopes and intercepts are significantly different from 0 at $P < 0.001$ inless noted with "ns." For F-values, the numerator and denominator degrees of freedom (ndf, ddf) are shown.

			All					
	Number in PP19 in 1992	Number in PP19 in 2021	Trend line equation	R^2	P	F (ndf, ddf)	Predicted number change over time (1992 to 2021)	Predicted % change over time (1992 to 2021)
All FS	50,583	36,399	Number = 779,842–368.48 (FY)	0.75	<0.001	83.99 (1, 28)	−10,686	–23%
Non-R&D FS	46,953	34,763	Number = 632,102–296.22 (FY)	0.67	<0.001	56.78 (1, 28)	−8,590	−20%
R&D FS	3,630	1,636	Number = 147,739–72.27 (FY)	0.91	<0.001	291.48 (1, 28)	−2,096	−55%
R&D Non HydroEFR Duty Stations	2,461	1,064	Number = 99,101–48.50 (FY)	0.92	<0.001	317.10 (1, 28)	−1,407	−57%
R&D HydroEFR Duty Stations	1,169	572	Number = 48,639–23.77 (FY)	0.87	<0.001	181.64 (1, 28)	−689	−53%
R&D Hydro Series (1315/1316)	75	43	Number = 2,138–1.03 (FY)	0.58	<0.001	38.88 (1, 28)	−30	−39%
All FS Grade 1–8	27,862	19,108	Number = 478,235–227.87 (FY)	0.66	<0.001	53.79 (1, 28)	−6,608	−27%
All FS Grade 9–12	18,868	13,582	Number = 308,513–145.9 (FY)	0.85	<0.001	164.54 (1, 28)	−4,231	−24%
All FS Grade 13–15, and 0	3,853	3,709		0.08	0.1225	2.54 (1, 28)		
R&D Grade 1–8	1,612	353	Number = 96,208–47.45 (FY)	0.95	<0.001	538.38 (1, 28)	−1,376	−82%
R&D Grade 9–12	1,167	800	Number = 30,818–14.84 (FY)	0.66	<0.001	54.63 (1, 28)	−430	−34%
R&D Grade 13–15, and 0	851	483	Number = 20,714–9.98 (FY)	0.87	<0.001	185.88 (1, 28)	−289	−35%
R&D Hydro EFR Duty Stations Grade 1–8	514	133	Number = 32,693–16.11 (FY)	0.91	<0.001	280.9 (1, 28)	−467	−79%
R&D Hydro EFR Duty Stations Grade 9–12	374	258	Number = 10,615–5.12 (FY)	0.64	<0.001	49.32 (1, 28)	−148	−36%
R&D Hydro EFR Duty Stations Grade 13–15, and 0	281	181	Number = 5,331–2.53 (FY)	0.69	<0.001	61.31 (1, 28)	−73	−26%
R&D Hydro Series Grade 1–8	35	19	Number = 866–0.42 (FY)	0.32	0.001	13.19 (1, 28)	−12	–33%
R&D Hydro Series Grade 9–12	24	14	Number = 1,011–0.49 (FY)	0.62	<0.001	45.46 (1, 28)	−14	−52%
R&D Hydro Series Grade 13–15, and 0	16	10	Number = 260–0.12 (FY)	0.26	0.004	9.88 (1, 28)	−4	−27%
Managers All FS	13,301	11,141		0.06	0.20	1.70 (1, 28)		
Managers Non-R&D	12,435	10,651		0.02	0.45	0.59 (1, 28)		
Managers R&D	866	490	Number = 19,408–9.32 (FY)	0.48	<0.001	26.02 (1, 28)	−270	–32%
Managers R&D HydroEFR Duty Stations	294	200						

acknowledge that the trends reported for the USDA Forest Service are likely different than those at other Federal, State and private institutions, and thus represent a microcosm of trends across the nation. Further work to uncover demographic trends at other agencies would complement the work reported here.

3.5. Voices of women of hydrology at EFRs

The "Past, Present and Future Women in Hydrology at EFRs" questionnaire offered the women associated with the HydroEFRs a unique opportunity to share their experiences. We located publicly available emails for 119 of the 180 women identified by the SICs. Of the 119, 44 responded to the "Past, Present and Future Women in Hydrology at EFRs" questionnaire (37% return rate; Table 4). The respondents were roughly evenly divided between those affiliated with the Forest Sericve and those affiliated with other agencies or universities. Most of the women (75%) were affiliated with the EFR at the time they completed the questionnaire. Approximately half the respondents were scientists

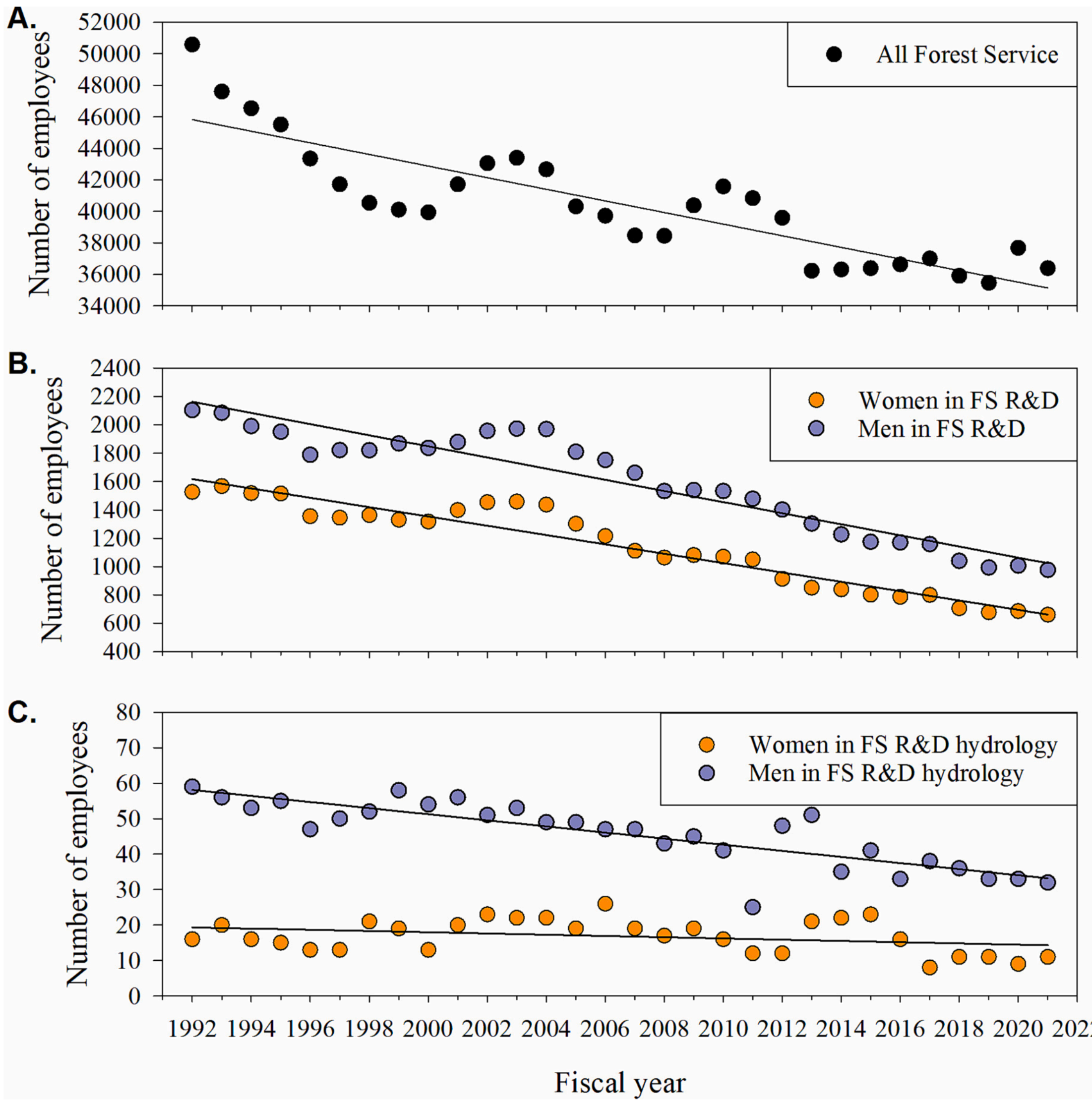

Fig. 8. Number of all employees in the Forest Service (FS) (A), all women and men in FS Research and Development (R&D) (B), and all women and men in FS R&D who are hydrologists and hydrologic science technicians (C), from 1992 to 2021 fiscal years. For trend line equations and statistics, see Tables 1 and 2.

(55%); 23% were technicians or other staff; 11% were other professionals, and 9% were students. The women who responded were or had been actively engaged in many aspects of the hydrologic sciences at their EFR. Ninety-three percent self-reported that they contributed to fieldwork, 73% to making new discoveries, 68% to writing manuscripts, 50% to information management, 50% to laboratory work, and 25% to other work in hydrology. They were also engaged in other activities at the EFR, with 64% contributing to training and mentoring others, 46% involved in giving tours, 43% involved in technology transfer with stakeholders, 39% helping to support the infrastructure at the site, and 20% contributing in other ways to ongoing science at their EFRs. The respondents, in general, had significant and regular interactions with other women. Of the 44 respondents, 27% of the respondents indicated they had 10+ other women in their hydrologic social network, 14% indicated that number was 6–10; 39% indicated that number was 3–5; 20% indicated that number was 1–2; and no respondent indicated that they had no other women in their hydrologic social networks. When asked “how often do you/did you collaborate(d) with other women at your EFR?”, with 1 being “hardly ever” and 5 being “every day,” 7% said “hardly ever,” 34% said “every day,” and the average score was 3.7.

Slightly more than half (57%) of the respondents reported they had had women as mentors; 43% said they had not. Of the 25 women who indicated they had women mentors, 22 identified that having a woman mentor influenced their careers. Fifty-five percent indicated that the mentors influenced their careers by providing “Support and encouragement,” 45% indicated that their mentors were a “Role model/ Inspiration,” 27% indicated that their mentors helped them “Navigate gender-based landscapes,” and 9% indicated that they had “Good male and female mentors,” which we interpreted as having a female mentor was not as important as having a mentor.

The respondents felt that they had made major contributions to hydrology. Thirty-six responded to a prompt on what they considered their major contribution to the field of hydrology. Of these, the most often cited contribution was related to “Improving understanding of hydrologic processes (69%), followed by “Contributing to the collection, curation, and stewardship of long-term data” (33%), and then “Contributions to land management” (22%). Also, the respondents were involved in many activities that contributed to the overall success of their EFRs. The top two categories were “Intellectual contributions to other scientific disciplines and studies” (40%), followed by “Contributing to collection, analysis, curation and stewardship of long-term data” (34%). Their third most mentioned other major accomplishment was contributing to the social capital of the EFR via “Teamwork/ networking/mentoring” (20%).

Table 2
Total numbers of employees for pay period (PP) 19 in 1992 and 2021 for all of the Forest Service (FS) and for the Research and Development (R&D) and non-R&D deputy areas by gender. Hydro Series is a category containing hydrologists and hydrologic science technicians (1315 and 1316 OPM series). Linear regressions predicting the number (y) of men or women employees by fiscal year (x = FY) are presented. All slopes and intercepts are significantly different from 0 at $P < 0.001$ unless noted with "ns.".

					Men						Women					
	Number men PP19 in 1992	Number men PP19 in 2021	Number women PP19 in 1992	Number women PP19 in 2021	Trend line equation	R^2	P	F (ndf, ddf)	Predicted number change over time (1992 to 2021)	Predicted % change over time (1992 to 2021)	Trend line equation	R^2	P	F (ndf, ddf)	Predicted number change over time (1992 to 2021)	Predicted % change over time (1992 to 2021)
All FS	31,330	24,246	19,253	12,153	Number = 395,356–184.24 (FY)	0.97	<0.001	957.27 (2, 57)	−5,343	−19%	Number = 384,458–184.24 (FY)	0.97	<0.001	957.27 (2, 57)	−5,343	−31%
Non-R&D FS	29,227	23,270	17,726	11,493	Number = 285,028–130.05 (FY)	0.97	<0.001	593.44 (2, 56)	−3,771	−15%	Number = 347,075–166.17 (FY)	0.97	<0.001	593.44 (2, 56)	−4,819	−30%
R&D FS	2,103	976	1,527	660	Number = 80,426–39.29 (FY)	0.94	<0.001	280.04 (3, 56)	−1,139	−53%	Number = 67,314–32.98 (FY)	0.94	<0.001	280.04 (3, 56)	−956	−59%
R&D Non HydroEFR Duty Stations	1,325	558	972	334												
R&D HydroEFR Duty Stations	696	320	473	252	Number = 29,859–14.61 (FY)	0.90	<0.001	171.84 (3, 56)	−424	−56%	Number = 18,780–9.16 (FY)	0.90	<0.001	171.84 (3, 56)	−266	−50%
R&D Hydro Series (1315/1316)	59	32	16	11	Number = 1,772–0.86 (FY)	0.92	<0.001	205.71 (3, 56)	−25	−43%	Number = 365–0.17 (FY)	0.92	<0.001	205.71 (3, 56)	−5	−26%
All FS Grade 1–8	15,152	13,608	12,710	5,500	Number = 25,810–6.26 (FY)	0.94	<0.001	312.47 (1, 56)	−181	−1%	Number = 452,425–221.61 (FY)	0.94	<0.001	312.47 (1, 56)	−6,427	−59%
All FS Grade 9–12	12,999	8,469	5,869	5,113	Number = 281,645–135.41 (FY)	0.97	<0.001	725.63 (3, 56)	−3,927	-33%	Number = 26,868–10.50 (FY)	0.97	<0.001	725.63 (3, 56)	−304	−5%
All FS Grade 13–15, and 0	3,179	2,169	674	1,540	Number = 57,998–27.68 (FY)	0.97	<0.001	708.72 (3, 56)	−803	−28%	Number = −64,904 + 32.96 (FY)	0.97	<0.001	708.72 (3, 56)	956	126%
R&D Grade 1–8	677	179	935	174	Number = 40,337–19.87 (FY)	0.94	<0.001	307.09 (3, 56)	−576	−77%	Number = 55,871–27.58 (FY)	0.94	<0.001	307.09 (3, 56)	−800	−85%
R&D Grade 9–12	695	476	472	324												
R&D Grade 13–15, and 0	731	321	120	162	Number = 23,957–11.68 (FY)	0.99	<0.001	1,303.43 (3, 56)	−339	−49%	Number = −3,244 + 1.70 (FY)	0.99	<0.001	1,303.43 (3, 56)	49	33%
R&D Hydro EFR Duty Stations Grade 1–8	231	64	283	69	Number = 14,768–7.28 (FY)	0.90	<0.001	166.92 (3, 56)	−211	−78%	Number = 17,924–8.84 (FY)	0.90	<0.001	166.92 (3, 56)	−256	−80%
R&D Hydro EFR Duty Stations Grade 9–12	224	135	150	123	Number = 8,033–3.91 (FY)	0.79	<0.001	70.83 (3, 56)	−113	−45%	Number = 2,582–1.21 (FY)	0.79	<0.001	70.83 (3, 56)	−35	−20%
R&D Hydro EFR Duty Stations Grade 13–15, and 0	241	121	40	60	Number = 7,057–3.42 (FY)	0.98	<0.001	975.93 (3, 56)	−99	−42%	Number = −1,726 + 0.89 (FY)	0.98	<0.001	975.93 (3, 56)	26	54%

(continued on next page)

Table 2 (*continued*)

	Number men PP19 in 1992	Number men PP19 in 2021	Number women PP19 in 1992	Number women PP19 in 2021	Men: Trend line equation	R^2	*P*	*F* (ndf, ddf)	Predicted number change over time (1992 to 2021)	Predicted % change over time (1992 to 2021)	Women: Trend line equation	R^2	*P*	*F* (ndf, ddf)	Predicted number change over time (1992 to 2021)	Predicted % change over time (1992 to 2021)
R&D Hydro Series Grade 1–8	27	14	8	5	Number = 441–0.21 (FY)	0.84	<0.001	152.61 (2, 57)	−6	−23%	Number = 425–0.21 (FY)	0.84	<0.001	152.61 (2, 57)	−6	−61%
R&D Hydro Series Grade 9–12	17	10	7	4	Number = 782–0.38 (FY)	0.67	<0.001	37.61 (3, 56)	−11	−62%	Number = 229–0.11 (FY)	0.67	<0.001	37.61 (3, 56)	−3	−34%
R&D Hydro Series Grade 13–15, and 0	15	8	1	2	Number = 445–0.22 (FY)	0.87	<0.001	126.95 (3, 56)	−6	−50%	Number = −185 + 0.09 (FY)	0.87	<0.001	126.95 (3, 56)	3	331%
Managers All FS	9,557	7,906	3,744	3,235												
Managers Non-R&D	8,933	7,605	3,502	3,046												
Managers R&D	624	301	242	189	Number = 17,080–8.28 (FY)	0.88	<0.001	141.95 (3, 56)	−240	−41%	Number = 2,328–1.04 (FY)	0.88	<0.001	141.95 (3, 56)	−30	−12%
Managers R&D HydroEFR Duty Stations	209	117	85	83	Number = 4,258–2.04 (FY)	0.79	<0.001	70.71 (3, 56)	−59	−29%	Number = −873 + 0.48 (FY)	0.79	<0.001	70.71 (3, 56)	14	16%

Some of the most colorful responses related to memorable moments experienced by the respondents while working at their EFRs. More than three-quarters of the respondents offered favorite memories, with the most often cited categories of favorite moments dealing with "Friendships, camaraderie and personal encounters" (56%), followed by overcoming adversity on a "Challenging field day" (35%), tales of "Teamwork" (26%), "Encounters with/Immersion in Nature" (24%) and "Aha/creative" moments (21% each). One respondent claimed to have no positive memory of her EFR.

Finally, the respondents reflected on a half-century of change for women in hydrology at EFRs, and described their visions for the future. The majority of the respondents (89%) reflected on how the number and roles of women in hydrology had changed at EFRs over the past 50 years, with the most frequently cited observation being that there were "More women in hydrologic research" (77%). This is consistent with the DMAT data which showed an increase in the ratio of women:men in the FS HydroEFRs. This was followed in frequency by comments that there was "More respect/acceptance for women of hydrology" (26%), and then a range of other comments including "More opportunities for research and collaboration for women" (10%) and "Change in role from office administrators to field staff" (10%). Only 8% thought there were more women in leadership roles, and 5% said they did not know. This is contrary to the DMAT data for the Forest Service that showed conclusively an increase in the number of women in leadership positions between 1992 and 2021, including at the HydroEFRs. More research on lags in recognition of demographic trends is warranted.

The respondents envisioned a more equitable future for hydrologic research. The most frequently cited vision for the future was simply that "More women will participate in hydrology at EFRs in the future" (57%). This was followed closely by comments that there will be "No need to consider gender issues of equal opportunity, access, respect and wages at EFRs in the future" (46%), and then by an expectation that there will be "More women in leadership roles at EFRs in the future (24%). Two respondents hoped that future considerations would shift from the binary male/female conversation to include individuals of non-binary physical or sexual orientation as well.

In sum, the voices of the women at the HydroEFRs who chose to share their experiences with us reflected a positive attitude towards their work at EFRs. In general, they were actively involved in many aspects of the EFRs from research to education and outreach and they were proud of their contributions to their EFRs. Most had networks of other women with whom they interacted frequently, and many listed their opportunity to network and for camaraderie as salient features of their experiences. Only about half indicated they had women mentors in their careers, although they generally found these mentors important to their career advancement and satisfaction. Increasing mentorship for women in hydrology may be an opportunity for the future. Finally, the women sensed that the numbers of women in hydrology had increased over time, and they wished for more equity for women in the future.

4. Conclusions

Our results show that HydroEFRs have played an important role in advancing the careers of women in the hydrologic sciences, who, in turn, have contributed to the groundbreaking hydrologic research that occurs at these long-term research sites. This is reflected in their 3,000$^+$ publications since 1977, their involvement in all aspects of the research cycle, and their "voices" of appreciation for their work at HydroEFRs. Further, HydroEFRs are important research and training sites not only for women in hydrology at FS R&D, but also for women in hydrology at cooperating agencies, universities and NGOs across the country.

At the Forest Service R&D, scientific capacity in general and for women specifically, has declined over the last 30 years, including a 59% decline in the numbers of women in the FS R&D workforce, 50% decline in the numbers of women in the HydroEFR workforce, and 26% decline in the numbers of women in the hydrologic series workforce. Such

Table 3
Ratio of the number of women employees to the number of men employees for pay period (PP) 19 in 1992 and 2021 for all of the Forest Service (FS), the Research and Development (R&D) deputy area, HydroEFRs within R&D, Hydro Series within R&D, which is a category containing hydrologists and hydrologic science technicians (1315 and 1316 OPM series), R&D Hydro EFR Duty Stations in higher-graded positions, Managers in R&D, and Managers at R&D HydroEFR Duty Stations. Linear regressions predicting the ratio of women to men employees (y) by fiscal year (x = FY) are presented for each category if the model was significant. All slopes and intercepts are significantly different from 0 at $P < 0.001$ unless noted with "ns." For F-values, the numerator and denominator degrees of freedom (ndf, ddf) are shown.

			Ratio of Women to Men				
	Ratio in PP19 in 1992	Ratio in PP19 in 2021	Trend line equation	R^2	P	F (ndf, ddf)	Predicted ratio change over time (1992 to 2021)
All FS	0.61	0.50	y = 8.49–0.004 *x	0.93	<0.001	378.87 (1, 28)	−0.11
R&D FS	0.73	0.68	y = 7.21–0.003 *x	0.70	<0.001	64.84 (1, 28)	−0.09
R&D Hydro EFR Duty Stations	0.68	0.79	y = −4.82 + 0.003 *x	0.19	0.01	6.70 (1, 28)	0.08
R&D Hydro Series (1315/1316)	0.27	0.34	ns	0.06	0.21	1.65 (1, 28)	
R&D Hydro EFR Duty Stations Grade 13–15, and 0	0.17	0.50	y = –22.19 + 0.011 *x	0.84	0.01	152.44 (1, 28)	0.33
Managers R&D	0.39	0.63	y = −14.15 + 0.007 *x	0.74	<0.001	80.01 (1, 28)	0.21
Managers R&D HydroEFR Duty Stations	0.41	0.71	y = −19.90 + 0.01 *x	0.67	<0.001	56.41 (1, 28)	0.30

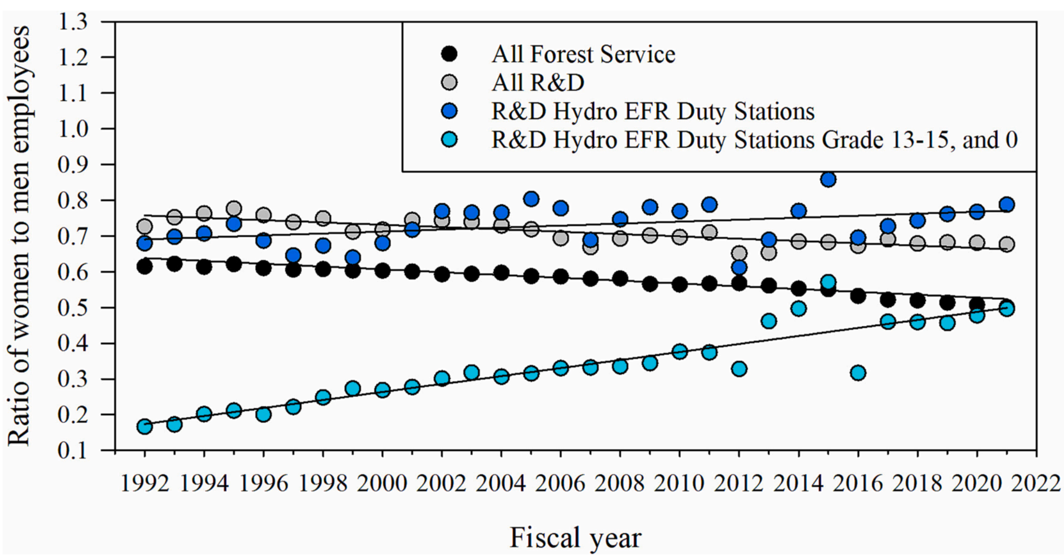

Fig. 9. Ratio of the number of women employees to men employees in the Forest Service (FS) (black), FS Research and Development (R&D) (grey), FS R&D HydroEFR Duty Stations (blue), and FS R&D HydroEFR Duty Stations who are in higher-graded positions (cyan), from 1992 to 2021 fiscal years. For trend line equations and statistics, see Table 3.

contractions are a threat to the ability of FS R&D to continue to sustain high-quality hydrologic research, training, and outreach; to mentor women in the existing workforce; and to attract qualified women to this workforce in the future.

Despite declines in numbers, the hydrologic workforce in FS R&D has maintained or increased its gender diversity over the last 30 years. Specifically, the ratio of women:men increased at the HydroEFRs (from 0.68 to 0.79). This was consistent with the 'voices' of the women of HydroEFRs, where nearly three quarters of the respondents thought there were more women at HydroEFRs now than in the past. This is in contrast to the declines in the ratio of women:men across the entire Forest Service and across FS R&D during this same period.

Further, despite the declines in numbers, the representation of women in higher-grade positions and leadership roles has increased across the entire Forest Service, across FS R&D and at HydroEFRs. The contributions of these women to increasing attention to gender-based issues, to serving as role models for other women both within and outside the Forest Service, and to shaping science in new ways requires further social science research.

As water crises around the world continue to escalate, building a strong workforce in the hydrologic sciences has never been more important. Research shows that diversity matters and that increasing the diversity of a workforce can spark innovation, improve performance, and lead to more effective problem-solving (Cheruvelil et al., 2014; Nielsen et al., 2017; Østergaard et al., 2011; Rice, 2011). Investment in a diversity of race, ethnicity, and gender remains a priority in STEM fields across the country in general and at the Forest Service specifically. The data presented here suggest that the representation of women in the FS R&D hydrologic workforce remains low and 2) investment in the EFRs as centers for research and training for women in hydrology and investments in attracting and retaining women in the field of hydrology may benefit this discipline. The "voices" of the women of HydroEFRs expressed a hope for a more equitable future and one where gender would no longer need to be a consideration.

Declaration of Competing Interest

The authors declare the following financial interests/personal

Table 4
Number of responses for employer, workforce participation, and job-related duties from a questionnaire to women who had contributed to hydrologic and environmental sciences at HydroEFRs in 2022.

Question	Choices	Affirmative Responses
Employer		
	Forest Service	23
	Other agency or institution	20
	Blank	1
Workforce		
	Current	33
	Past	11
Primary Role at EFR		
	Scientist	24
	Technician/Staff	10
	Student	4
	Other professional	5
	Blank	1
Worked related to hydrology at EFR		
	Making new discoveries	32
	Information management	22
	Publishing manuscripts	30
	Field work	41
	Laboratory work	22
	Other	10
Work related to other non-hydrological programs at EFR		
	Tours	20
	Training/mentoring	28
	Technology transfer	19
	Infrastructure support	17
	other	9

relationships which may be considered as potential competing interests: Lindsey Rustad reports financial support was provided by USDA Forest Service Northern Research Station. Chelcy Miniat reports financial support was provided by USDA Forest Service Rocky Mountain Research Station. Margaret Gregory reports financial support was provided by USDA Forest Service. Salli Dymond reports financial support was provided by University of Minnesota.

Data availability

The authors do not have permission to share data.

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Special contributions to special issue on women in hydrology

All authors are women. LR, SFD, MBA and CFM are mid- to late career; MG is early career. None of the authors is a mentor/mentee of the other authors. LR, SFD, MBA and CFM all contributed equally to research design, data collection, data analysis, modeling, writing, interpretation, and/or editing. MG contributed to research design and editing.

Appendix A. Supplementary data

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