

1 **COVID-19 Impacts Highlight the Need for Holistic Evaluation of Research and in the**  
2 **Hydrologic Sciences**

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11 **Authors:**

12 CUAHSI Board of Directors & Officers

13  
14 **Corresponding author:**

15 Adam S. Ward

16 O'Neill School of Public and Environmental Affairs

17 Indiana University

18 418 MSB-II

19 Bloomington, IN 47405

20  
21 Email: adamward@indiana.edu

22 Phone: 812-865-4820

23  
24 **Abstract**

25 As we reckon with the effect of COVID-19 on the research enterprise in hydrologic science, it is  
26 important to acknowledge that disruptions will be persistent and that institutional-level  
27 adjustments, while helpful, are not sufficient to mitigate all impacts on hydrologic scientists.  
28 Here, we describe the breadth of research contributions in the hydrologic sciences, consider  
29 how the pandemic has impacted this portfolio of contributions, document one impact that is  
30 already being realized in publication of research, and suggest guidance to the hydrologic  
31 science community, institutions, review panels, and funding organizations in considering these  
32 impacts at various stages of hiring and promotion in our community. Acknowledging the  
33 diversity of contributions to research is particularly valuable because it provides a more  
34 objective, transparent, and holistic basis for evaluating individuals within the context of norms of  
35 the hydrologic science community. With clearly established values, it is easier to identify  
36 impacts of life events, such as those related to the COVID-19 pandemic, as they are manifested  
37 in individuals under a diversity of circumstances.

38  
39 **Key Points**

- 40 1. Hydrologists' research contributions are diverse, not limited to publications  
41 2. COVID-19 pandemic disrupted and required reprioritization of research efforts  
42 3. Hydrologists should have actionable, meaningful plans on how to incorporate pandemic  
43 impact statements in promotion and hiring decisions  
44

45  
46 The impacts of the COVID-19 pandemic on research have been widespread, severe, and will  
47 continue to require consideration in the evaluation of research productivity over the lifespan of  
48 hydrologists' research careers (e.g., National Academies, 2021; Aubry et al, 2020; Malisch et al,  
49 2020; Shillington et al, 2020; Krukowski et al, 2021; Sotto-Santiago et al, 2021). As we reckon  
50 with the effect of COVID-19 on the global research enterprise and individual researchers, it is  
51 important to acknowledge that impacts may be persistent and that institutional-level adjustments  
52 (e.g., extended tenure clocks), while helpful, may not be sufficient to mitigate all impacts on  
53 hydrologic scientists. At the same time, the pandemic occurred against the backdrop of a  
54 broader discourse in higher education about the evolving nature of what constitutes scholarly  
55 activity and how increasingly diverse contributions should be valued and evaluated (e.g., Klein  
56 and Falk-Krzenski, 2017; National Academies, 2015; Klenk and Meehan, 2015; Montoya et al.  
57 2020; Davies et al. 2021) Thus, our objective in this commentary is to describe the breadth of  
58 research contributions in the hydrologic sciences, consider how the pandemic has impacted this  
59 portfolio of contributions, document one impact that is already being realized in publication of  
60 research, and to suggest guidance as to how these impacts could be taken into account at  
61 various stages of hiring and promotion in our community.

62  
63 Acknowledging the diversity of contributions to research is particularly valuable because it  
64 provides a more objective, transparent, and holistic basis for evaluating individuals within the  
65 context of norms of the hydrologic science community. A holistic evaluation is one that  
66 recognizes that advances in scientific fields can take many forms and may be shared and  
67 communicated in many ways. It recognizes the impact of research beyond simply counting  
68 publications; it looks to see how that research shapes our understanding of nature, our  
69 management practices, or the future direction of our field. With clearly established values, it is  
70 easier to identify impacts, such as those related to the COVID-19 pandemic, as they manifest,  
71 rather than leaving individuals to assert the impacts on an ad-hoc basis for their present and  
72 future careers. Establishing holistic evaluations in the hydrological sciences will also support  
73 individuals facing either future individual-level or societal-level challenges or disruptions to their  
74 research programs.

75  
76 This comment refines and builds upon a statement from the leadership of the Consortium of  
77 Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI, 2021), adding empirical  
78 data and raising its visibility to the community. As the Board and officers of an organization that  
79 represents and serves the hydrological science community, we are uniquely positioned to  
80 provide this perspective and to inform hiring, promotion, tenure and other evaluative bodies  
81 about the norms, expectations, and values in our community.

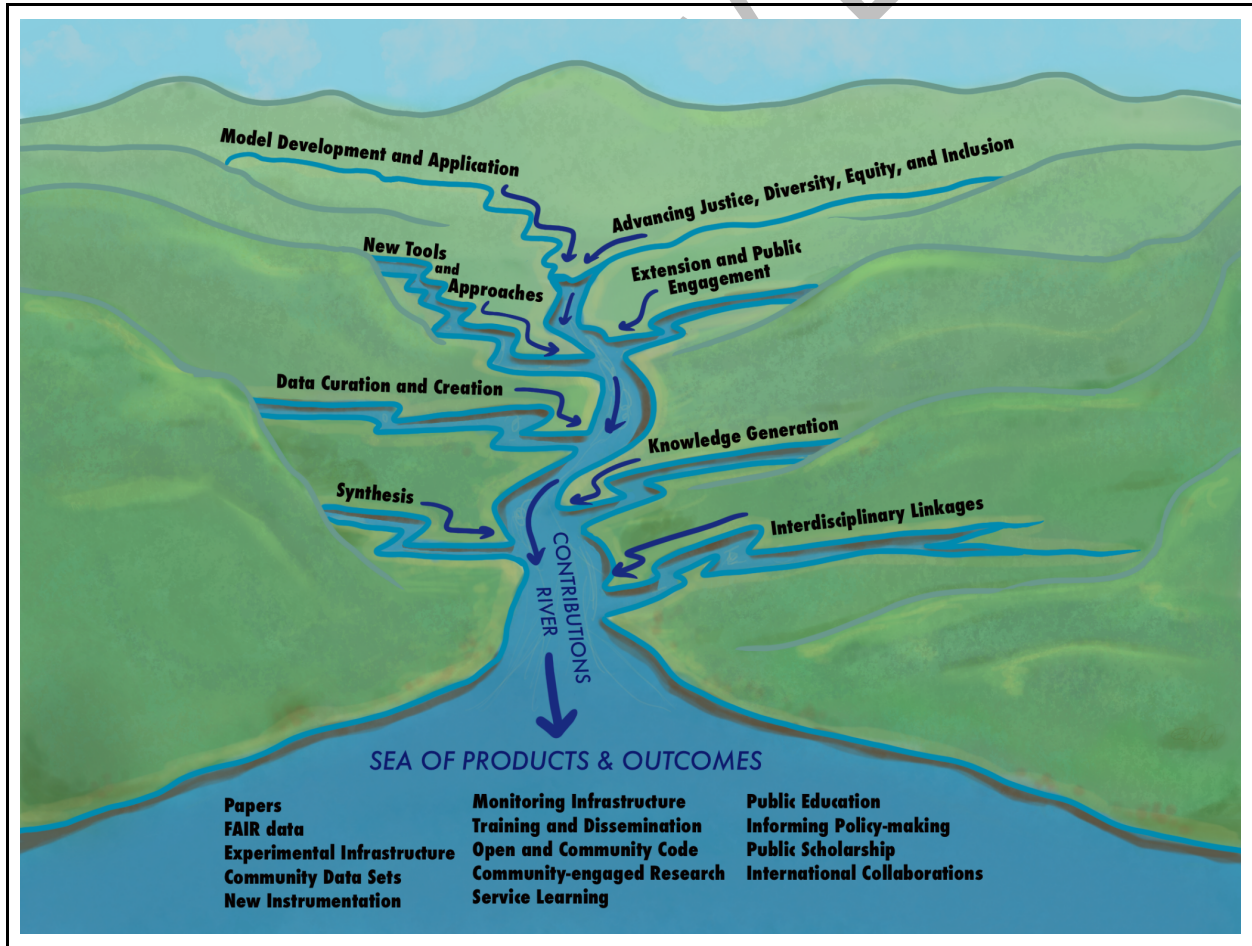
### 82 83 ***Hydrologists' research contributions are diverse***

84 Advancement of the hydrologic sciences requires progress in diverse arenas (Fig. 1), and the  
85 types of contributions by researchers in the hydrologic sciences vary substantially from  
86 individual to individual. While each individual's portfolio will be unique and will involve different  
87 activities, it is critical to recognize that many types of research contributions are valued by our  
88 community. Notably, the balance and weighting of these activities will vary as a function of

89 individual, institution, and position. Still, acknowledging the breadth of research contributions in  
90 our field provides a framework to organize our understanding of not only the holistic  
91 contributions, but also the interconnected impacts of life-events such as a pandemic.

92  
93 In addition to traditional research products (e.g., manuscripts, books and book chapters,  
94 competitive funding), other products and services are valued as research outputs in hydrologic  
95 science (Fig. 1). We seek to articulate research outputs and activities that are consistent with  
96 types of contributions we value as a discipline, but which may not always be fully  
97 acknowledged in hiring, promotion, and tenure decisions. During the pandemic, the effort to  
98 sustain research efforts (e.g., the integrity of long-term data sets and experiments) may have  
99 been prioritized over more traditional research products. For example, the hydrologic scientist  
100 who maintained the integrity of a long-term data set or experiment will have faced substantial  
101 challenges in logistics, safety planning, approvals, and working alone when teams would have  
102 traditionally worked in close proximity. Thus, the pandemic has precipitated an urgent need to  
103 document the range of contributions that we value in our field. The full breadth of these  
104 endeavors must be accounted for as we assess the productivity of individuals in light of  
105 COVID-19 and beyond.

106



**Fig. 1.** Hydrologic science relies upon diverse research contributions from our community

(terrestrial system, above). Examples of contributions valued in the field include: (1) **Generating new knowledge**: improved understanding of hydrologic processes and generation of new theory describing these processes. (2) **Interdisciplinary linkages and feedbacks**: efforts to merge hydrologic theory with knowledge from allied disciplines to understand synergistic and symbiotic processes, including those that may occur at physical and disciplinary boundaries. (3) **Data creation**: generation, curation, and sharing of data from field and laboratory studies, which are a cornerstone of development of hydrologic understanding. (4) **Synthesis efforts**: synthesis of place-based studies into generalizable frameworks and the proactive testing of transferability of models and techniques. (5) **Development of new tools, techniques, and approaches**: the development, validation, and sharing of new methodologies and technologies for observing the hydrologic cycle, and the effort to proliferate these across the community. (6) **Model development and use**: physical, numerical, and statistical modeling approaches to interpret and forecast hydrological processes, including model development, building computational infrastructure, and using models to inform decision-making. (7) **Applied research, extension, and public engagement**: the transfer of hydrologic science to practice through applied research, extension, and public engagement. We value the time, skill, and expertise required to conduct or co-create timely research-based knowledge and share via cooperative extension programs and through policy engagement. (8) **Advancing diversity, equity, inclusion, and justice**: the contributions that advance justice in hydrologic science in broad ways including for environmental justice and to ensure greater diversity, equity, and inclusion within our community. These contributions (the watershed and stream network) contribute to a host of products and outcomes (only examples of which are explicitly pictured above), all of which are valued by our community. See CUAHSI (2021) for additional details and further examples.

107

### 108 ***Effects of pandemic disruptions on hydrologic sciences research***

109 While many of the commonly identified impacts of the pandemic on scientific research are  
110 mirrored in the hydrologic sciences (e.g., loss of lab access, cancellation of conferences), we  
111 believe it important to articulate some specific examples through which these disruptions are  
112 manifest and are particularly acute in the hydrologic sciences. Below we provide a non-  
113 exhaustive list of examples to help readers envision the specific impacts on research within the  
114 hydrologic sciences. We identify six major categories of impacts on hydrologic science  
115 research:

- 116 1. *Hydrologic sciences research is sensitive to temporal disruptions.* Missing an important  
117 event such as snowmelt, postponement of field experiments, and interruption of long-  
118 term data sets, including those collected by government agencies, challenged  
119 scientists during the pandemic.
- 120 2. *Hydrologic sciences research is sensitive to disruptions in site access and travel.* Many  
121 field sites and lab facilities continue to impose access restrictions. Travel to maintain  
122 field sites, collect data to validate sensor deployments, visit collaborators, conduct  
123 interviews or focus groups, and execute field experiments were limited or severely  
124 altered during the pandemic.
- 125 3. *Hydrologic sciences research is dependent on access to large-scale or distributed*  
126 *equipment.* Loss of access to shared infrastructure included reductions in coordinated  
127 deployment of specialized equipment (e.g., airborne data collection) and prioritization of  
128 COVID-related research on large-scale computing facilities.

- 129 4. *Hydrologic science is a multi-disciplinary collaborative field.* Pandemic conditions  
130 reduced opportunities to build collaborations through conferences, workshops, and site  
131 visits. Reduced density requirements meant students entered lab groups working  
132 remotely, and early career scientists contended with building collaborative networks  
133 and research groups in an online-only environment and limited collaboration,  
134 consultation, and information gatherings.
- 135 5. *Experimental and lab-based hydrologic research was disrupted by loss of access to*  
136 *research labs and maker spaces.* For example, access to lab spaces was restricted by  
137 many institutions, preventing experiments and sample analyses from being conducted  
138 during the pandemic and challenging the establishment of labs by early career  
139 researchers. Labs and lab supplies were repurposed to pandemic efforts.

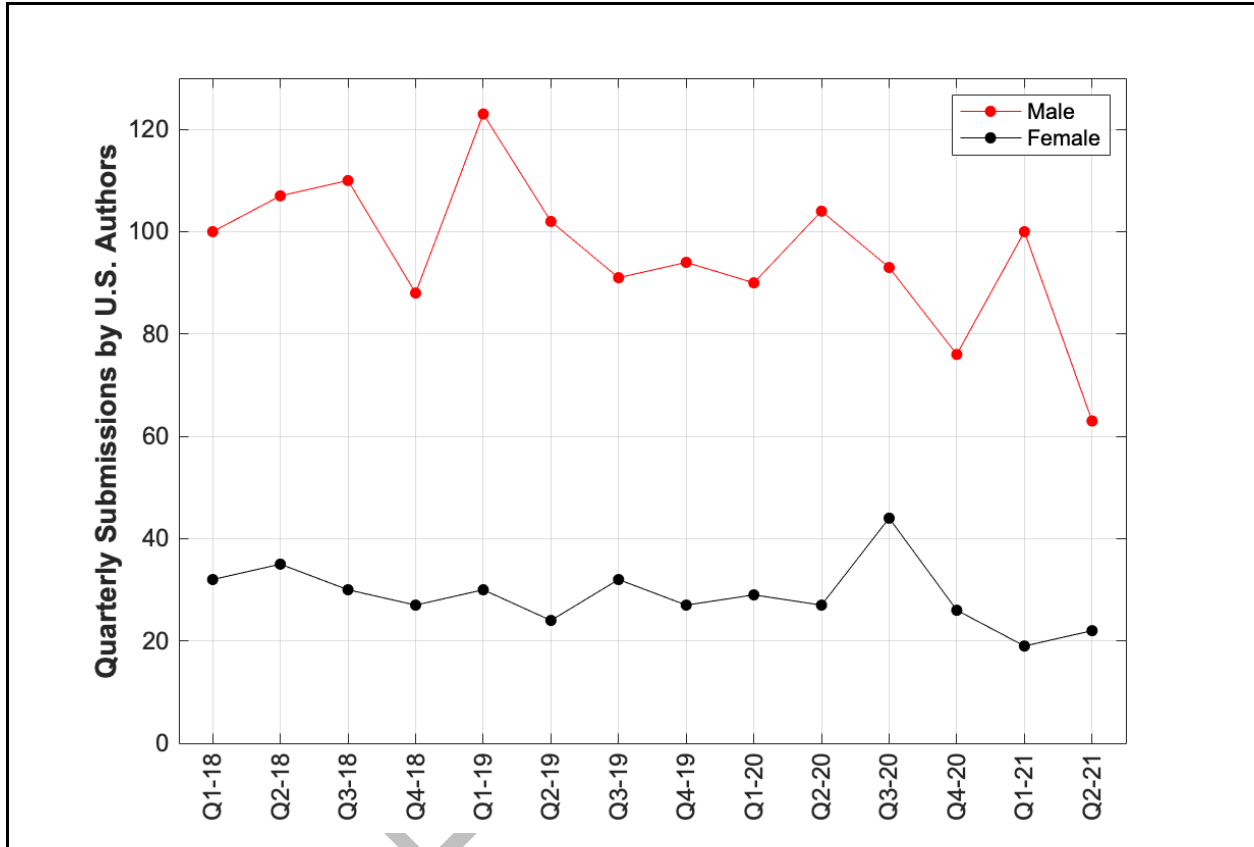
#### 141 **Early evidence of COVID-19 impacts at Water Resources Research**

142 To assess early evidence of the pandemic's impact on hydrologic science, we analyzed  
143 submissions to *Water Resources Research* from January 2018 through June 2021. First, we  
144 found evidence that submittals from female corresponding authors in the U.S. (the most  
145 represented country of origin for authors in our data set) were increased (Q3-20) or held steady  
146 early in the pandemic (Q4-20), consistent with reports that time spent on writing increased as  
147 time spent in the lab, field, and elsewhere decreased (Gonzales and Keane, 2020a; 2020b).  
148 Subsequently, these submissions decreased to their lowest levels in the period analyzed during  
149 Q1- and Q2-21. We interpret this decrease as an indicator of pandemic impacts across a  
150 demographic known to be disproportionately impacted by the pandemic (e.g., Myers et al. 2020;  
151 Viglione, 2020). Declines in productivity are also apparent across overall submissions, with  
152 projected 2021 submissions below pre-pandemic (2018-19) levels for the U.S., Australia,  
153 Canada, China, and the Mexico, Central, & South America grouping (Fig. 3). Finally, we  
154 acknowledge here that other demographics will have been disproportionately impacted (e.g.,  
155 primary caregivers, families for whom education of children was disrupted), but data on these  
156 demographics were not available for analysis.

157  
158 These trends suggest that research that was in an earlier phase when the pandemic began is  
159 now missing from the publication pipeline and it remains to be seen what proportion of this early  
160 stage research has been merely delayed or entirely aborted. We anticipate that submittals from  
161 some demographics may remain depressed for up to several years as the research slowed or  
162 stalled during the pandemic matures toward publication. Further, the return to pre-pandemic  
163 working conditions will not occur uniformly in time. Instead, access to vaccines, both in a global  
164 context (e.g., variability in access to vaccines in different locations) and relative to individual  
165 circumstances (e.g., primary caregiver for a person who cannot be vaccinated), will be  
166 differential in the immediate future.

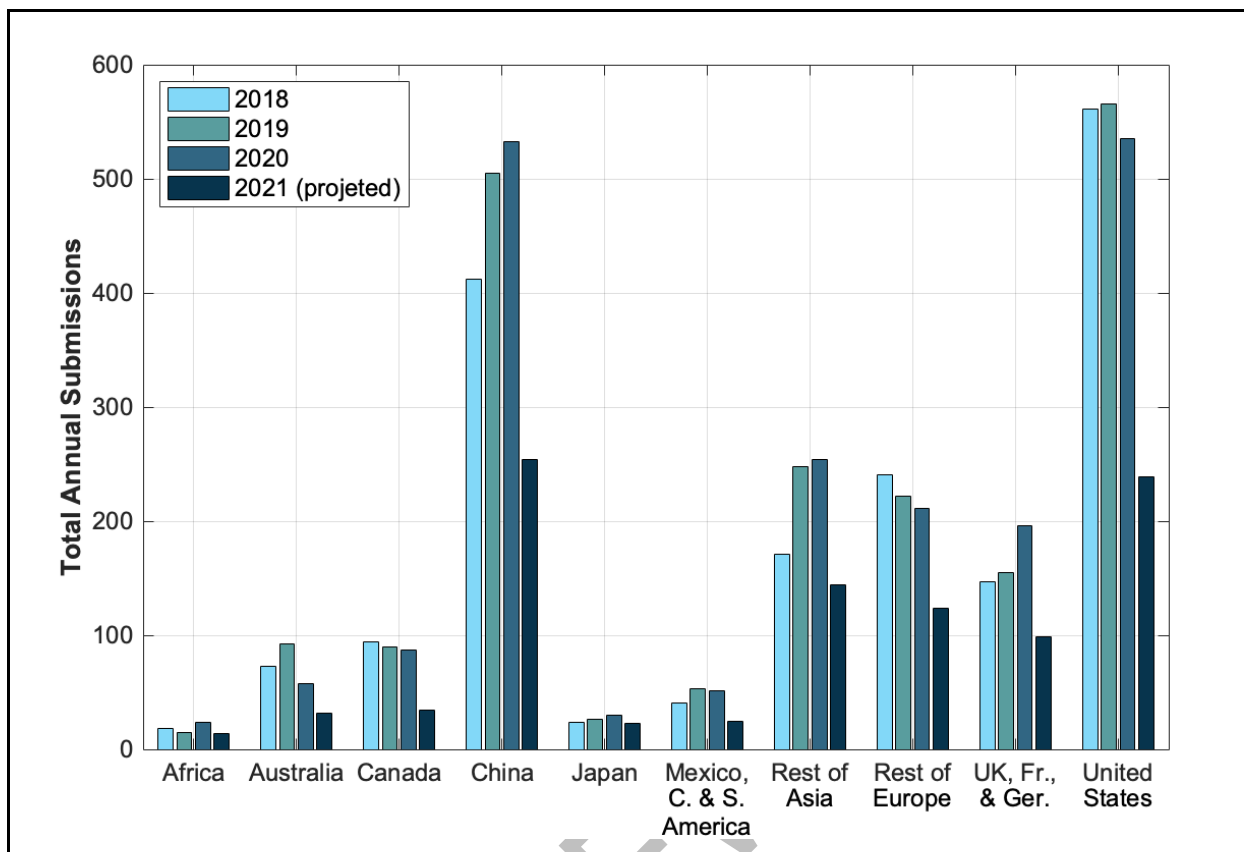
167  
168 A decline in publication productivity due to the pandemic has the potential to manifest later as a  
169 'less productive' CV for some individuals if not interpreted in context of (a) the pandemic's  
170 impact on research, and (b) the unequal impact across demographic groups and parts of the  
171 world. Importantly, we underscore that analysis of submittals to this journal is but one indicator  
172 of impact on one (itself not homogenous) demographic group in one geographic location and

173 does not represent the totality of impact on any individual. Instead, we present this as  
174 representative of the breaking wave of impact that we expect will be felt for the next decade or  
175 longer, and as early evidence that the pandemic's effects are real, measurable, and therefore  
176 cannot be ignored.  
177



**Fig. 2.** Quarterly submission of papers submitted to *Water Resources Research* (published by the American Geophysical Union, AGU) by U.S.-based lead authors. The precipitous drop in submittals during the pandemic (since Q3-2020) is an early signal of the lack of new research being completed during the pandemic.

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**Fig. 3.** Annual submissions to Water Resources Research based on country of residence for the corresponding author. Declines in submittals from the U.S. - the most represented country of origin in the data set - were apparent in 2020 and are projected to further decline in 2021. Declines in 2021 relative to pre-pandemic years (2018-19) are also projected in Australia, Canada, China, and the Mexico, Central, and South America grouping.

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***Suggestions to the community to ensure the holistic evaluation of hydrologic scientists***

The types of contribution and impacts outlined above and elsewhere (CUAHSI, 2021) provide a basis for the field of hydrologic science to consider how we evaluate candidates in a more holistic manner. This is particularly important as the pandemic impacts likely are only beginning to be fully realized and will ultimately have shaped and defined the essential training and/or early years in research for our present students, post-doctoral researchers, and early career faculty. How, then, shall we acknowledge and more importantly account for both the diversity of contributions to research in hydrologic science and the disparate impacts on individuals' training and careers?

*To those applying for positions, promotions, and/or tenure:* Consider directly articulating your past, present, and potential contributions across the breadth of research areas and products that are valued by our community. Explicitly describe impacts across the breadth of research contributions and products that are valued by our community (Fig. 1).

196  
197 *To external evaluators, reviewers, and those in positions to hire:* Evaluations should be  
198 written in the context of COVID-19 impact, acknowledging the acute and long-lasting  
199 impacts on the candidate. Recognize that the contributions hydrologists value and products  
200 they generate should not be considered a checklist for assessment, but instead a  
201 demonstration of the diverse ways that contributions are made and documented in our field.  
202 In evaluation letters, consider it your obligation to discuss the hydrology-specific issues  
203 related to the COVID-19 pandemic that were faced by the candidate and contextualize  
204 these experiences in the discipline. It is essential to highlight impacts that may not have  
205 been ubiquitous across all disciplines to educate review committees whose composition  
206 frequently spans a diverse array of intellectual backgrounds.  
207  
208 *To review committees and senior faculty:* We encourage you to ask for statements about  
209 COVID-19 impacts on research, teaching, mentoring, and service and to take seriously the  
210 concerns raised by candidates and reviewers. Do this with care and intent as impact  
211 statements require significant time and effort. You play an incredibly important role,  
212 intermediary to candidates and administrators, that can provide important context about the  
213 impacts of the pandemic. With the breadth of research contributions and products in our  
214 discipline, candidates' experiences may not have mirrored your own. Importantly, while we  
215 may all 'look like hydrologists' to other disciplines, the specific needs and impacts in our  
216 field are highly variable across our areas of expertise.  
217  
218 *To academic and professional leaders:* Voice support for the inclusion of the full breadth  
219 of research products and contributions that are valued in our discipline and consider how  
220 COVID-19 impacted them. Inclusion of this information, with guidance, and explicit  
221 requests asking for consideration of how COVID-19 impacted the candidate should be  
222 considered requisite in external review requests and internal review processes. Finally,  
223 recognize that -- while often helpful and appreciated -- extended tenure clocks or delays  
224 of mandatory merit and promotion review may not adequately or equitably address all  
225 possible long-term impacts of the pandemic (Manchester et al., 2013). The effects of  
226 COVID-19 on hydrologic science researchers are non-uniform. Consequently, uniform  
227 policies to address these impacts may exacerbate inequalities. Instead, particular focus  
228 should be given to support groups that have been especially impacted, and care taken to  
229 address individuals' needs rather than apply generic, universal policies.  
230  
231 *To funding agencies:* Program officers should continue to proactively engage with their  
232 communities to understand pandemic impacts and identify creative ways to mitigate the  
233 impacts. Agencies should consider differential COVID-19 impacts across subdisciplines in  
234 allocating recovery funds among disciplines, programs, and projects. Future review panels  
235 should explicitly consider COVID-19 impacts as research progress, products, and experience by  
236 PIs may have been delayed or diminished.  
237  
238 In summary, taking a holistic approach to evaluate and recognize the diverse and critical ways  
239 that hydrologists contribute to the hydrological sciences is necessary in light of the COVID-19



240 pandemic. Holistic evaluation will help hydrologists navigate and mitigate the impacts of COVID-  
241 19 and provide a consistent basis for evaluation of hydrologists. Our response as a discipline to  
242 the COVID-19 pandemic, and acknowledgement of the breadth of research types and products  
243 in our community, also provides a basis for evaluating impacts from other individual- or society-  
244 level disruptions that cause hydrologists to prioritize some investments of time over others.  
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